Earthrise from Lunar Reconnaissance Orbiter

NASA Goddard Thermal Technology Overview 2016

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NASA Goddard

Spacecraft Thermal Control Workshop
Aerospace Corporation
El Segundo, CA
22 March, 2016

Outline

- NASA’s budget and how it impacts Technology
- What’s happening at NASA HQ - Technology Roadmapping 2014
- Missions at Goddard
- Thermal challenges with GSFC Missions
- Emerging thermal control technologies
- Summary

FY16: Where is the budget going?

- The trend is UP! **FY14** - \$17.65B, **FY15** - \$18.01B, **FY16 - \$19.28B**
  - This is \$756M above the President's request
- **NASA FY16 Budget Proposal (in millions of dollars)**

• SCIENCE	\$5,589.4
– – Earth Science	\$1,921.0
– – Planetary Science	\$1,631.0
– – Astrophysics	\$730.6
– – JWST	\$620.0
– – Heliophysics	\$649.8
• SPACE TECHNOLOGY	\$686.5
• AERONAUTICS	\$640.0
• EXPLORATION	\$4,030.0
• SPACE OPERATIONS	\$5,029.2
• SAFETY, SECURITY, AND MISSION SERVICES	\$2,768.6
• OTHER	\$541.3

- **TOTAL \$19,285.0**

*2016 – Looks like we have turned the budget corner for NASA's Budget**

** at least for now*

Notes on Budget

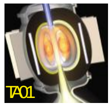
- Some of the biggest winners in the FY16 budget are: planetary science, the exploration program (including the Space Launch System and Orion), and commercial crew.
  - Congressional action for a mission to Jupiter's moon Europa; $175M. Congress wants 2022 launch, and mission to include an orbiter and lander! This is well beyond current planning for Europa Clipper
  - Long-term habitation module for Orion
  - Full funding for commercial crew
  - Space Technology – of the $686.5M $133M is directed for a satellite servicing project (RESTORE-L)
- President’s request for FY17 is $19.025B - $260M less than FY16 approved budget.
  - Proposed for FY17: revolutionize aeronautics with “New Aviation Horizons” program. This is a new generation of flight demonstration vehicles, also known as “X-planes.”

What else is happening regarding technology?

- New set of **Technology Roadmaps** approved and released by NASA's Office of the Chief Technologist
- *TA14; Thermal Management Systems* updated and expanded
  - New format, more searchable(e.g., technology snapshots)
  - Capability driven focus; much more closely tied to missions
- Separate presentation later in this Workshop on the details of the 2015 TA14 Technology Roadmaps

http://www.nasa.gov/offices/oct/home/roadmaps/index.html

2015 Space Technology Roadmap Technical Areas

TA01 
- LAUNCH PROPULSION SYSTEMS

TA02 
- IN-SPACE PROPULSION TECHNOLOGIES

TA03 
- SPACE POWER & ENERGY STORAGE

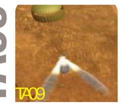
TA04 
- ROBOTICS, TELE-ROBOTICS & AUTONOMOUS SYSTEMS

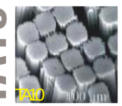
TA05 
- COMMUNICATION & NAVIGATION

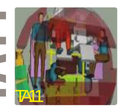
TA06 
- HUMAN HEALTH, LIFE SUPPORT & HABITATION SYSTEMS

TA07 
- HUMAN EXPLORATION DESTINATION SYSTEMS

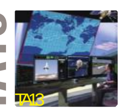
TA08 
- SCIENCE INSTRUMENTS, OBSERVATORIES & SENSOR SYSTEMS

TA09 
- ENTRY, DESCENT & LANDING SYSTEMS

TA10 
- NANOTECHNOLOGY

TA11 
- MODELING, SIMULATION, INFORMATION TECHNOLOGY & PROCESSING

TA12 
- MATERIALS, STRUCTURES, MECHANICAL SYSTEMS & MANUFACTURING

TA13 
- GROUND & LAUNCH SYSTEMS PROCESSING

TA14 
- THERMAL MANAGEMENT SYSTEMS

TA15 
- AERONAUTICS

Space Weather Tech

Autonomous Systems & AI Enhancements

Avionics Tech Enhancements

Radiation Tech Enhancements

Information Technology Section Expanded

Include NITRD and more

Orbital Debris TA5, TA7, TA10

Additional Crosscutting document
- Crosswalks – e.g., All Technical Areas that include Information Technology (IT), Radiation, avionics, etc.
- Dependencies

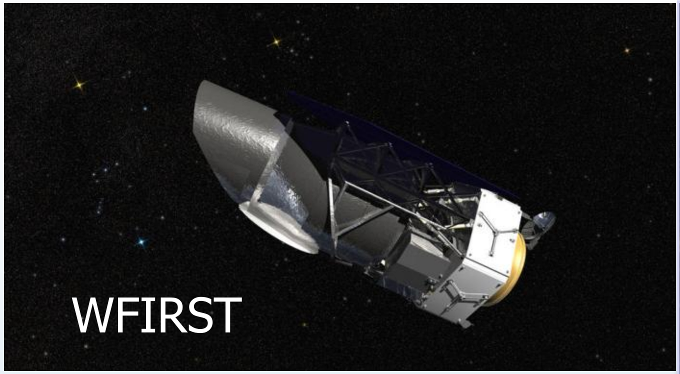
What else is happening regarding technology?

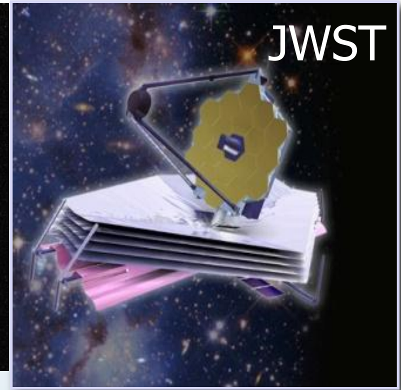
- **TechPort** - NASA HQ released NASA's Technology Portfolio System ; an integrated, Agency-wide software system designed to capture, track, and manage NASA's portfolio of technology investments.
  - Detailed information on individual technology programs and projects
  - Allows extensive search capability and sharing of information
  - Provides NASA HQ with tools to analyze the technology portfolio, make decisions about future investments, and generate reports quickly
  - About 900 entries currently – more coming continuously
  - Effort is in response to congressional legislation

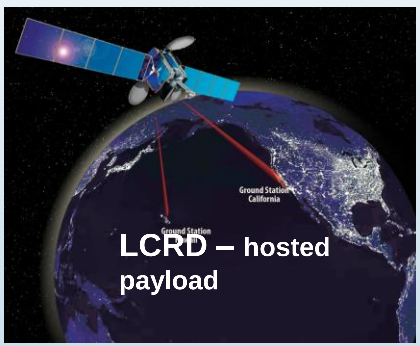
http://techport.nasa.gov

- **Top level:** HQ’s goal is to manage technology development more at a corporate level
  - GAO audits
  - Consolidation of Center capabilities
  - Increased collaboration

NASA GSFC Future Missions

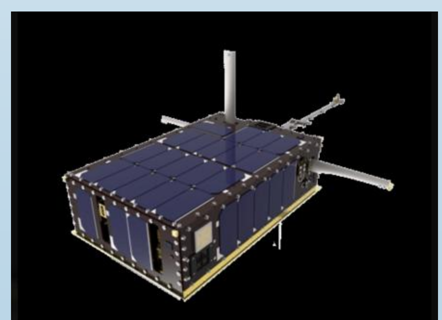




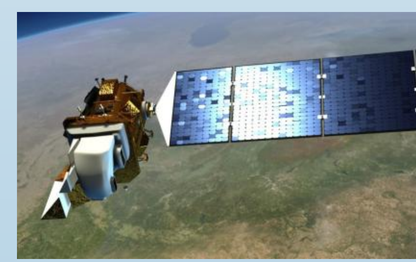


GOES-R

JPSS



CUBE-SATS



Landsat 9

Current Missions at Goddard

- **<u>Missions recently launched</u>;**

  - **MMS – 4 satellites - Explore Earth's Magnetic Field, launched in Mar 2015 It looks like one of the satellites may have been hit by micrometeorite or debris, still working OK.**

  - **DSCOVR – Launched in Feb 2015 arrived at L-1 in June 2015, looks at Space Weather, SpaceX launch vehicle**

  - **Orbital Antares ISS commercial servicing from Wallops. Pad being refurbished, Orbital using Atlas 5 for next 2 launches, then new Russian engines for Antares at Wallops. Plan to ramp up in 2016**

  - **ASTRO-H – Cryogenic instrument on Japanese satellite, launched in Feb 16. Achieved new low temp of 50 milli-Kelvin**

Current Missions at Goddard

- **<u>Missions in Work</u>:**
  - **ICESat-II (2017) – Uses lasers to measure polar ice sheet thickness (or lack there-of)**
  - **TDRS – next launch in 2017**
  - **LCRD – Laser Communication Relay Demo – new S/C host, DOD Tech-Demo mission, launch in 2017**
  - **OSIRIS-REX – Asteroid sample return, OVIRS cryogenic instrument at GSFC, launch in 2016**
  - **Landsat 9 follow on mission to Landsat 8 approved for new start, includes TIRS-2 instrument in-house at GSFC**
  - **MOMA instrument on European Mars Rover, launch in 2018**
  - **PACE/OCI - Ocean Color Instrument in-house at GSFC**
  - **Several Cubesats in work**

Current Missions at Goddard (cont.)

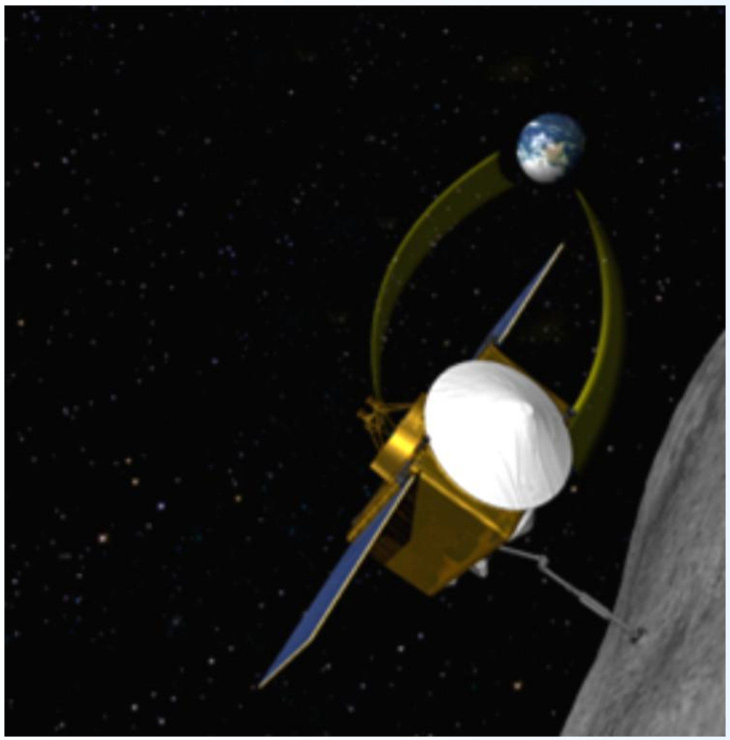
- **<u>Missions in Work</u>:**
  - **GOES-R - next generation of Geosynchronous weather satellites, launch in late 2016. Completed complicated TV test.**
  - **JPSS – Joint Polar Satellite System – NPP follow-on Weather Satellite launch in 2017, Ball S/C. JPSS – 2 instruments in work, S/C will be built by Orbital**
  - **RESTORE L - Robotic Mission to refuel Landsat 7, launch in 2019**
  - **WFIRST – Dark Energy mission, to use "Hubble like" telescope from DOD, launch in the 20's. Proceeding into Phase A**
  - **JWST – Large Telescope Mission scheduled for launch in 2018 Very challenging thermally, testing underway, recently completed 3rd cryogenic TV test of ISIM instrument assembly at GSFC, 4 month test.**

Current Missions at Goddard (cont.)

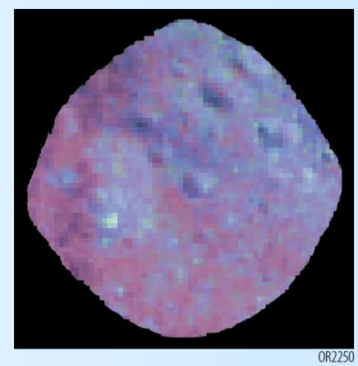
- **<u>ISS Missions</u> – push to fly Science payloads on Space Station. Extra thermal challenges include numerous configurations and analysis cases, 6 hour no-power case, manned mission safety requirements**
  - **NICER – X-ray Science Mission – uses passive cooling and Phase Change Material to survive the no power case, Launch in 2017**
  - **CREAM – Flight of Cosmic Ray experiment - managed out of Wallops. Utilizes JEM active cooling loop, completed I&T, awaiting launch**
  - **GEDI – uses lasers to analyze vegetation, JEM active cooling, at PDR, Launch in 2019**
  - **RRM3 – Robotic Refueling Mission utilizing methane – demonstrate ability to refuel satellites, launch 2018**

Thermal Challenges within Current Missions

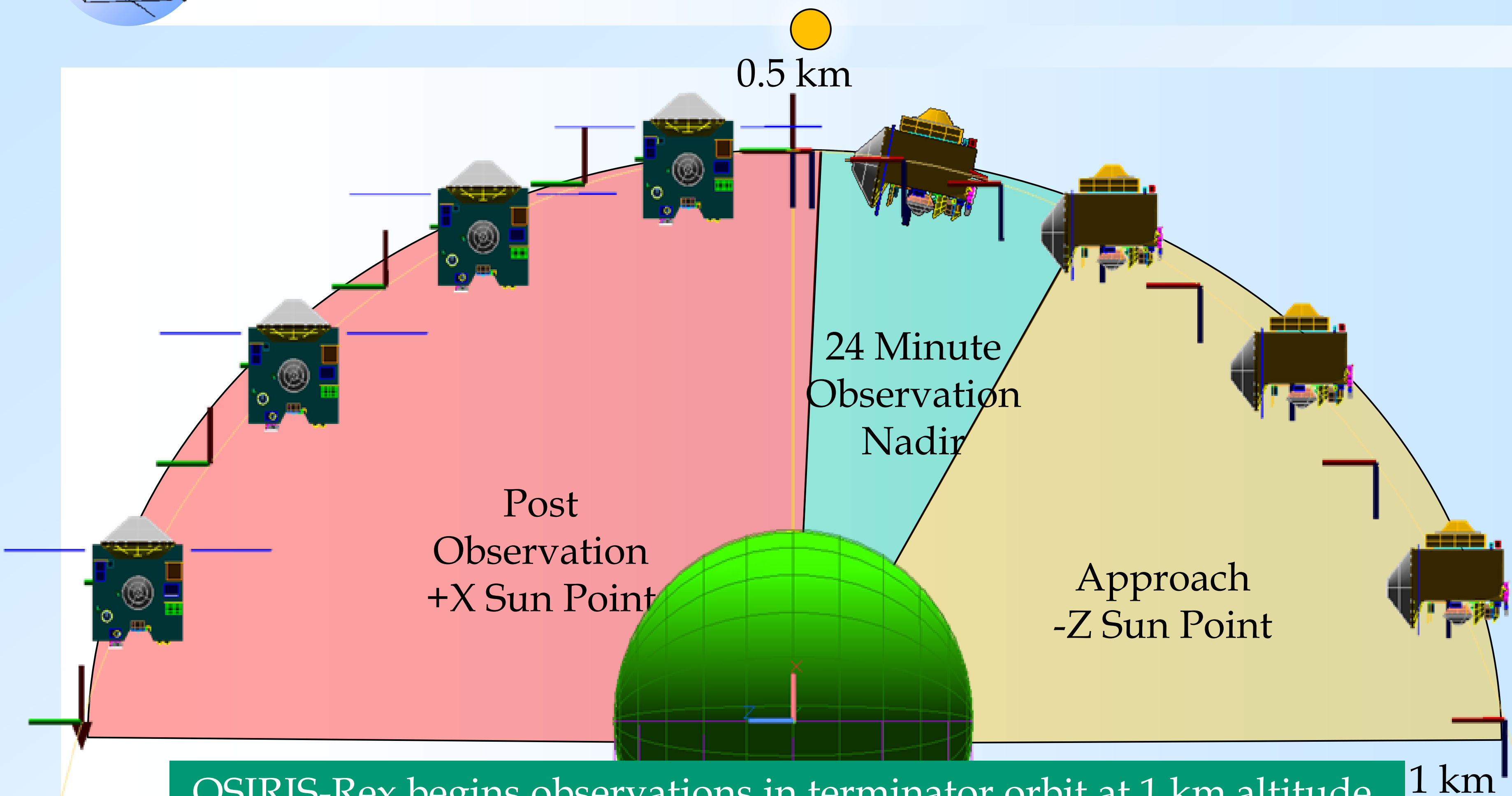
OSIRIS-REX – Asteroid Sample return



Asteroid Bennu

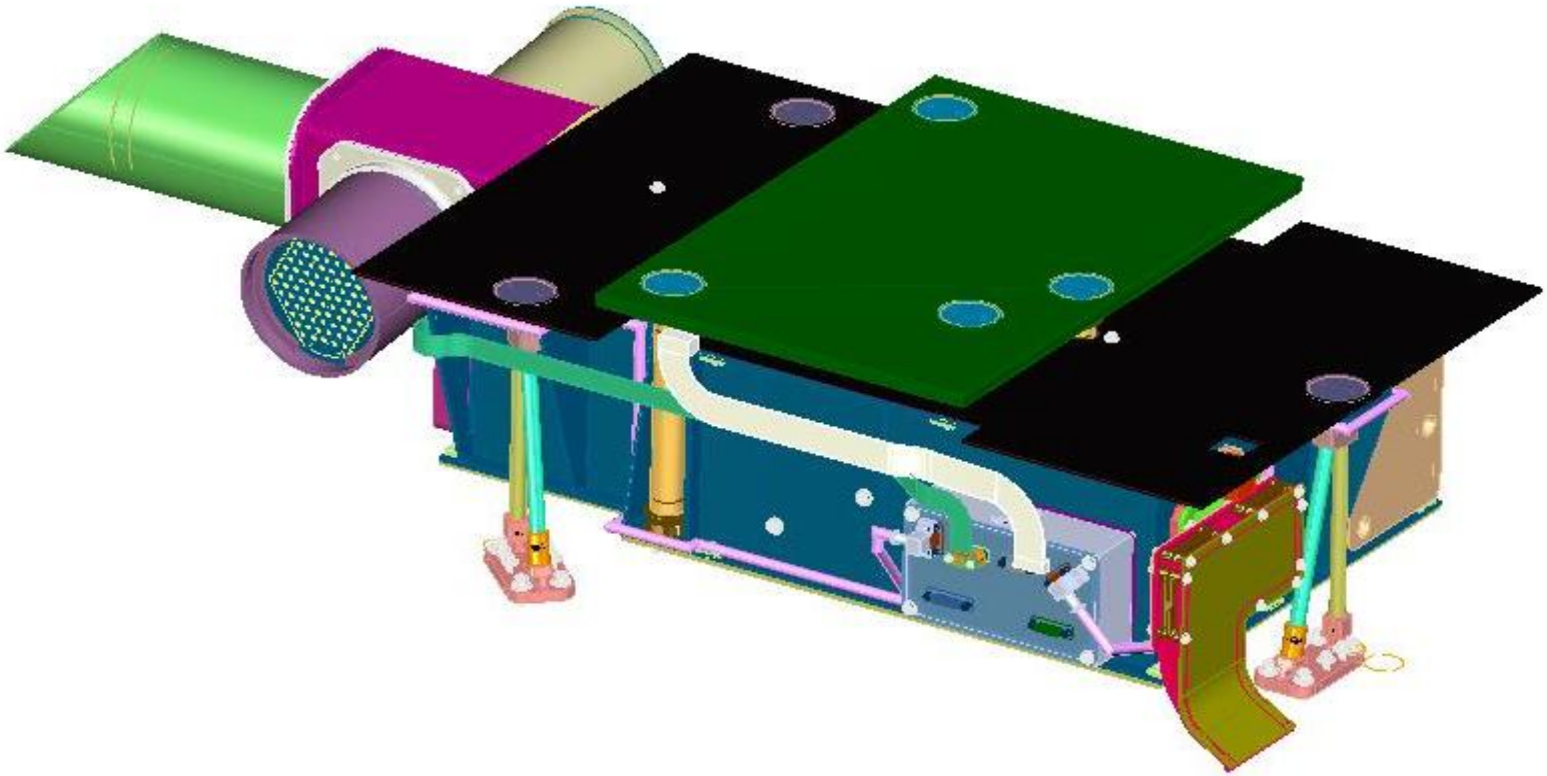


OSIRIS-REx Mission: Reconnaissance



OSIRIS-Rex begins observations in terminator orbit at 1 km altitude, returning to +X sun point upon completion of observation.

OSIRIS-REX OVIRS Instrument



Detector temp near 75 K, optics at 130 C, relies on 2 stage radiator (passive) and heat straps
"Orbits" asteroid, relies on transient behavior to meet requirements

OVIRS Instrument TV Testing

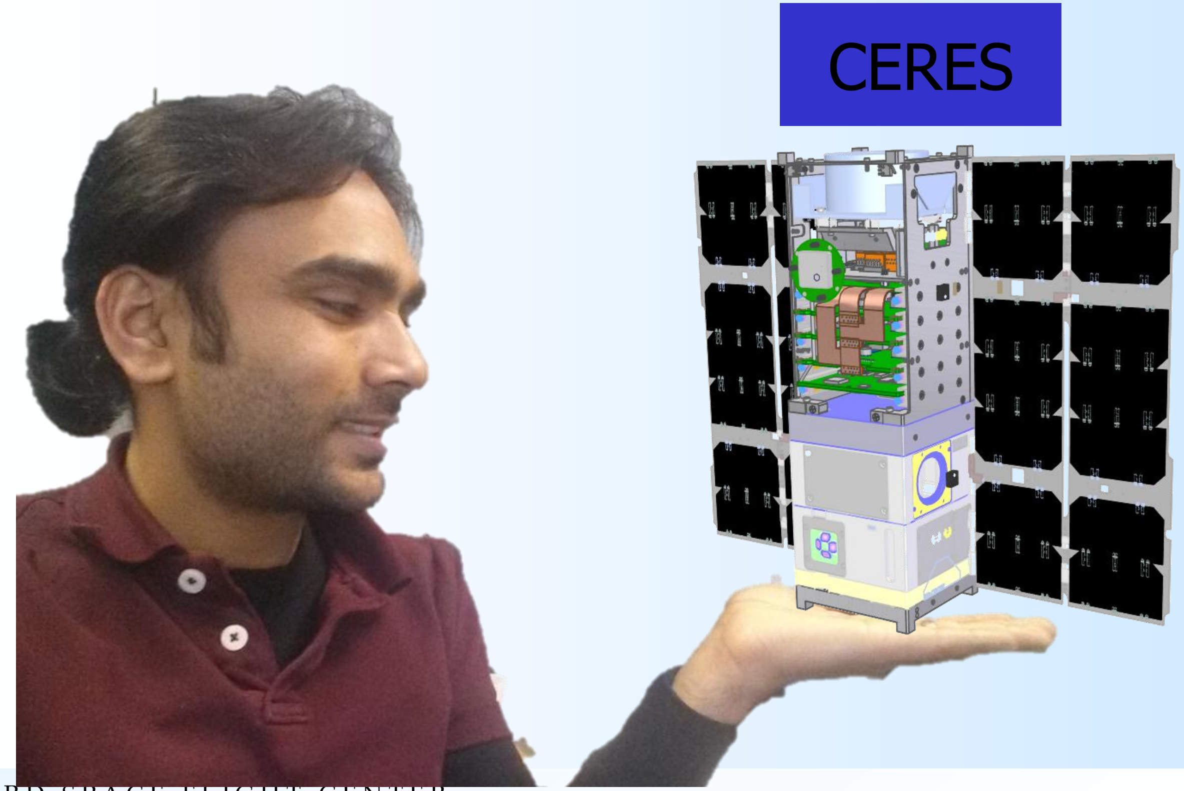
- During TV testing Detectors ran much warmer than expected
- Additional heat leaks from Copper harness EMI shielding and mounting bracket redesign not in model
- EMI shielding material changed to Stainless Steel
- Sun shield added to Spacecraft to reduce heat load
- Detector Temperature limit raised due to extra margin in the design

Lessons Learned:

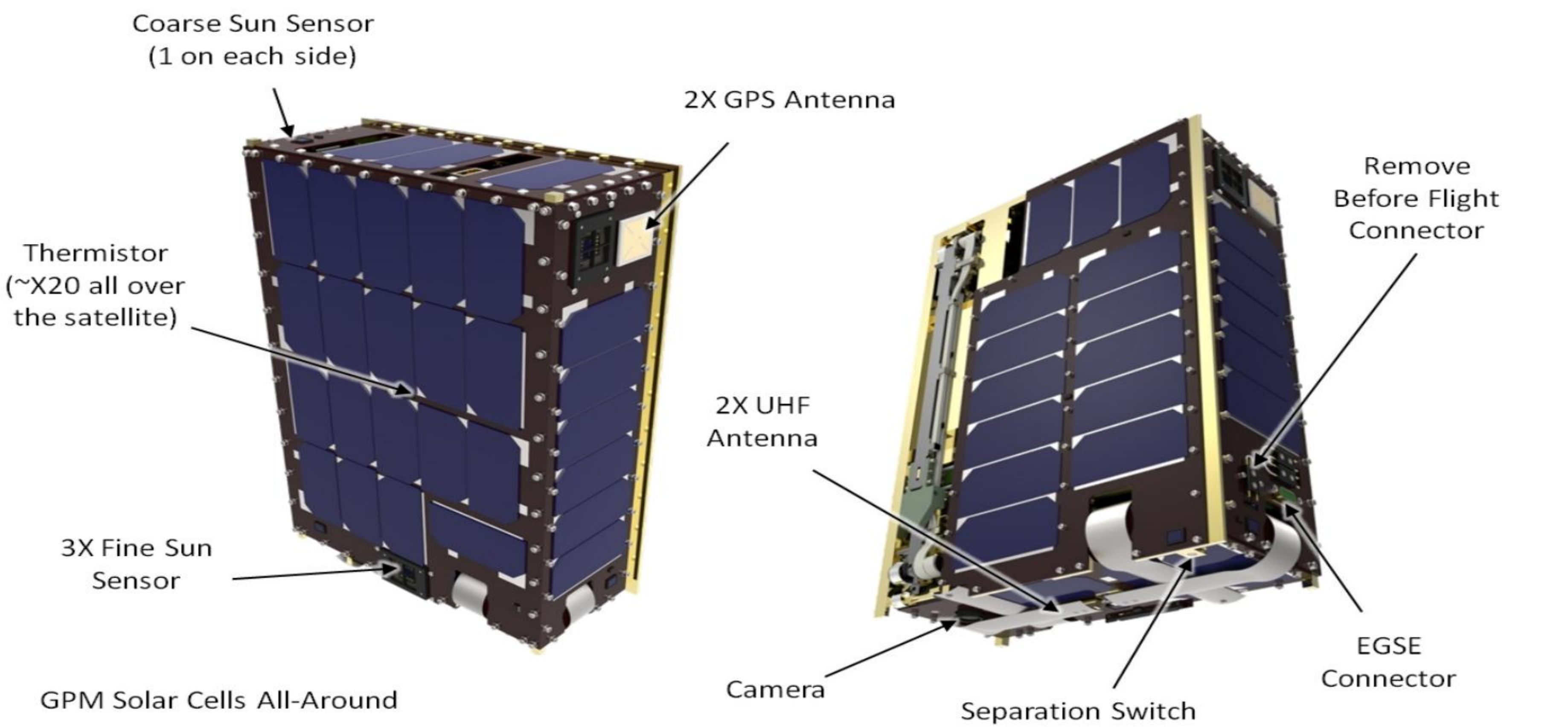
- Every heat leak is important on cryogenic instruments
- Need Good communication on project team
- Can sometimes push back on Science requirements

Cubesats at GSFC

3U CERES will study the interaction between our Sun and the Earths radiation belt.

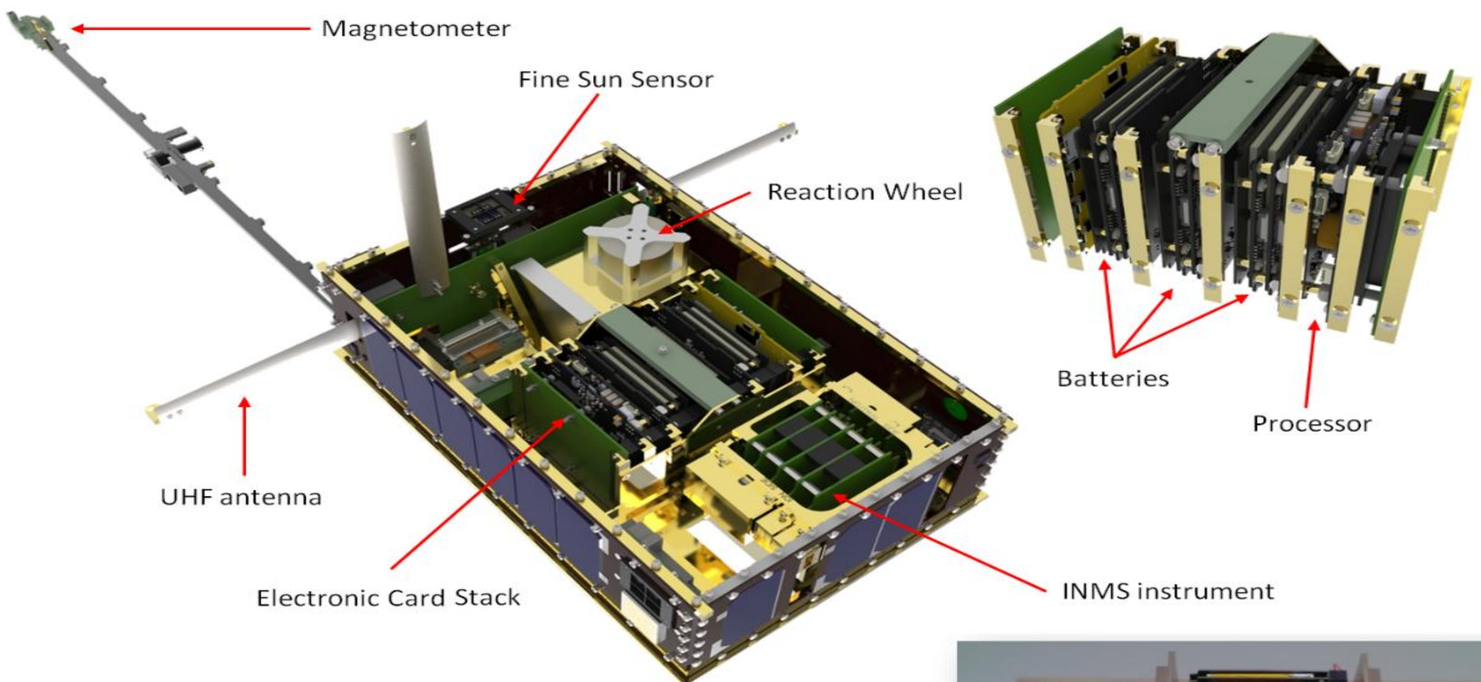


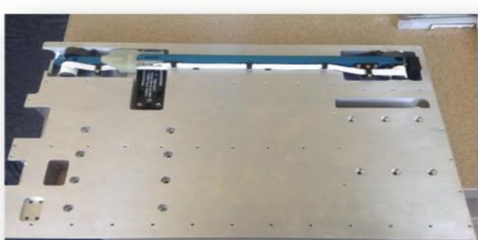
Dellingr 6U CubeSat

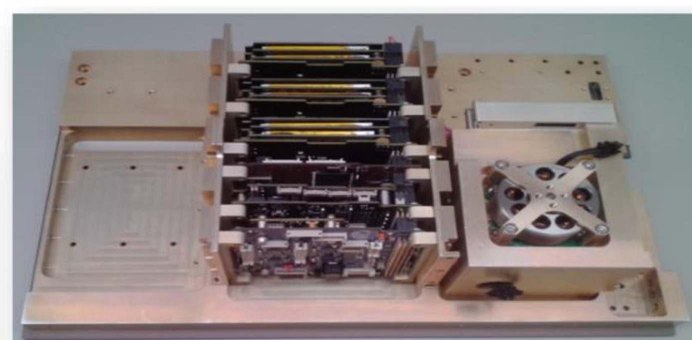


Cubesats at GSFC

Dellingr Inside Layout

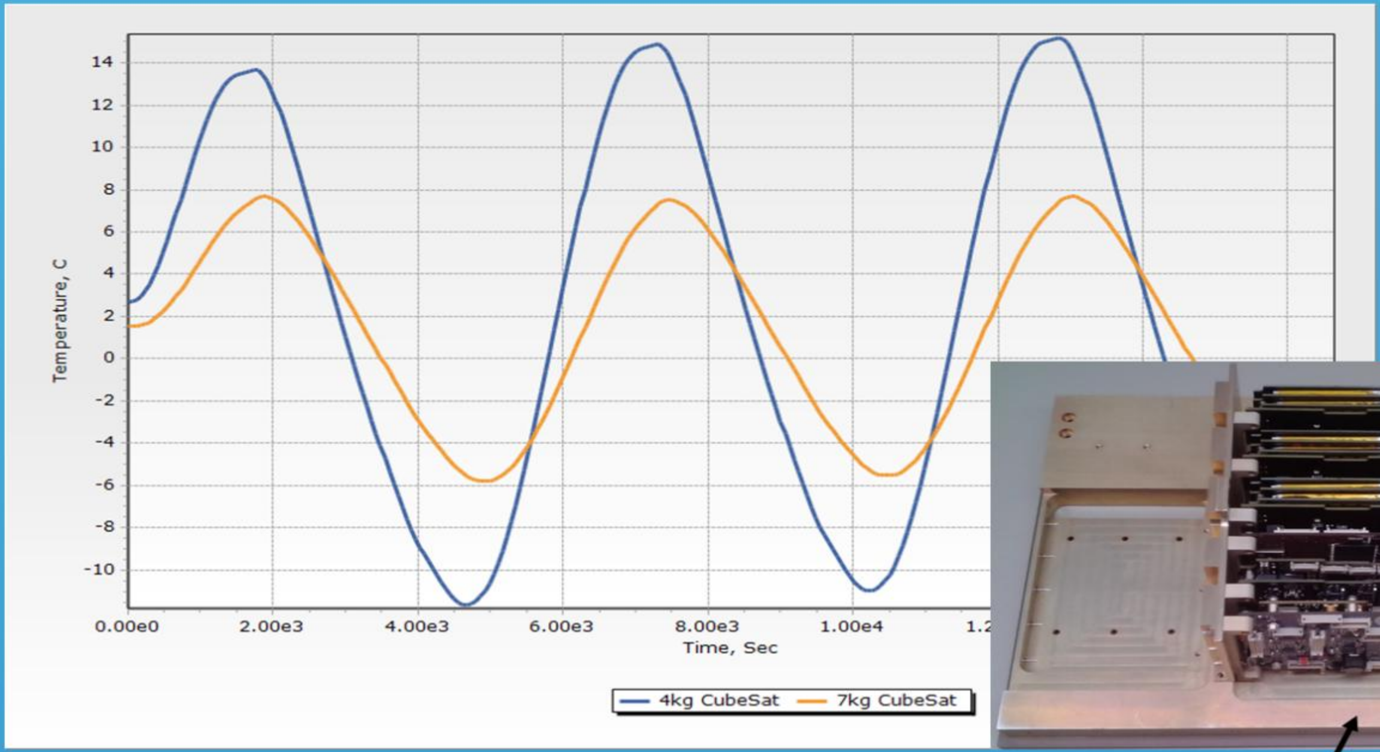


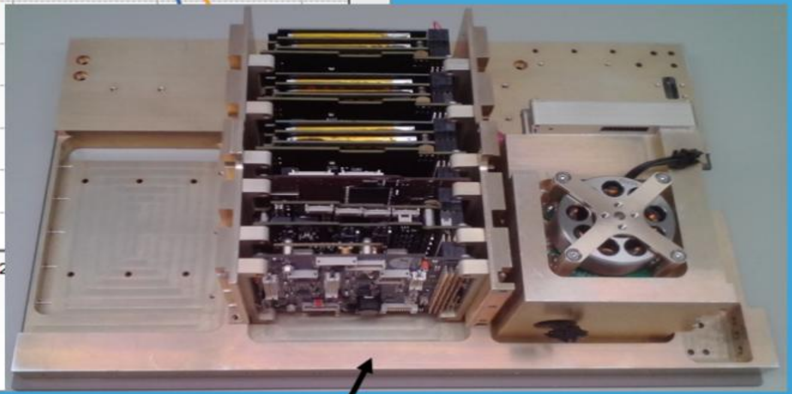




Cubesats at GSFC

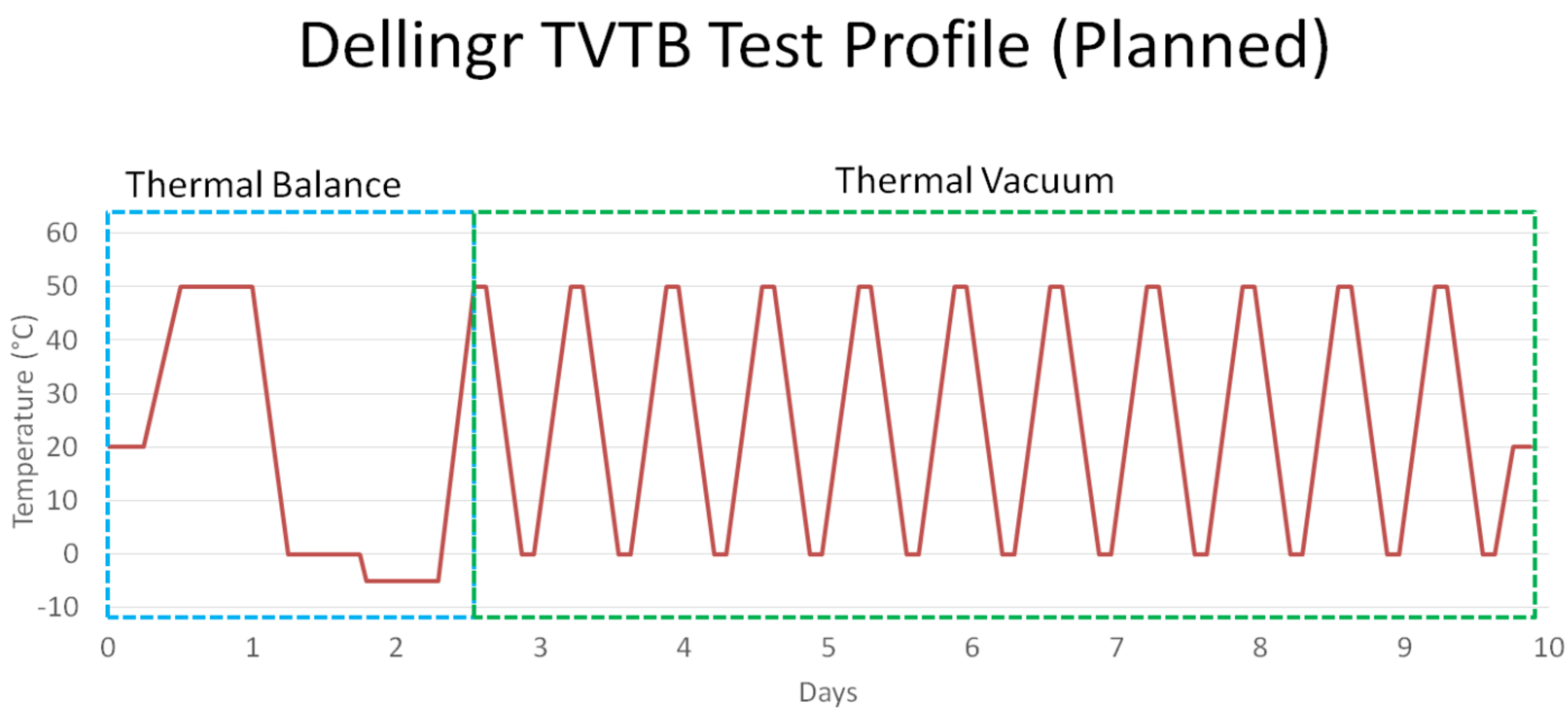
Design Recommendation: Increase thermal mass





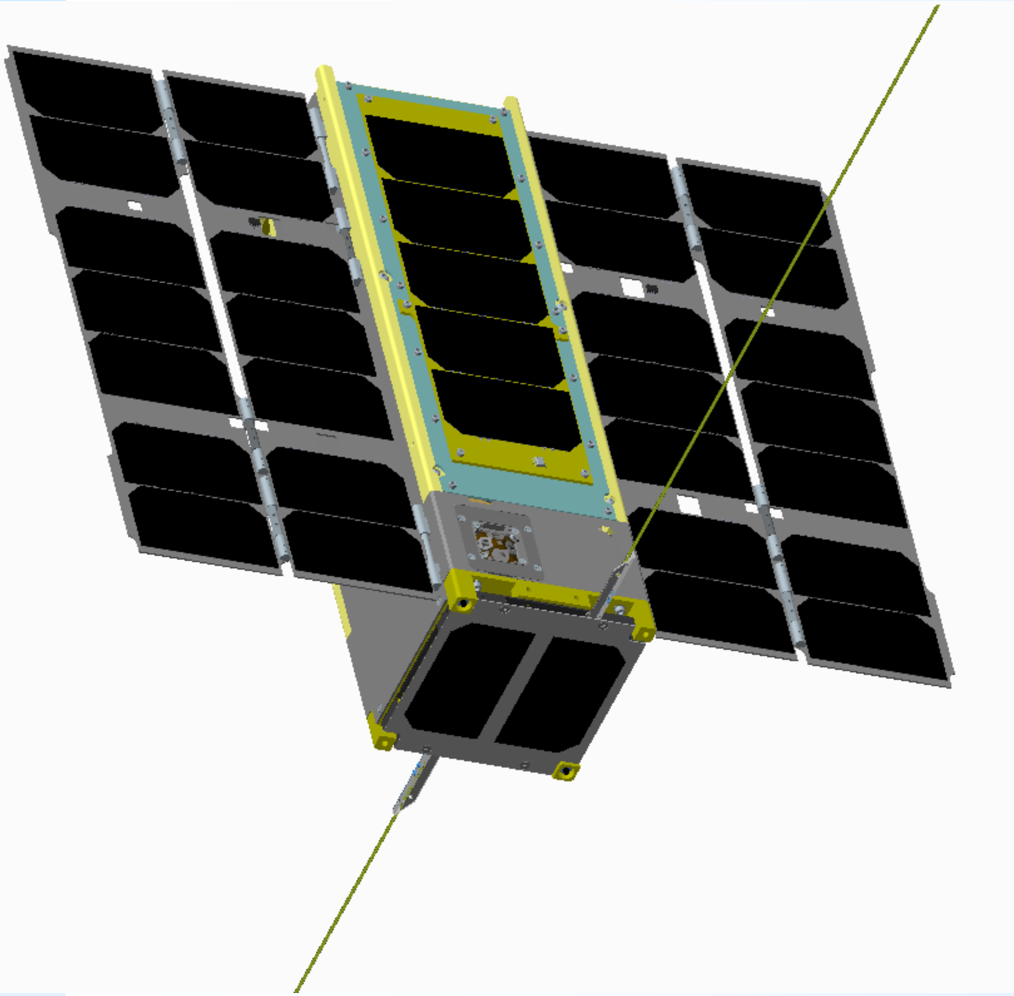
- Transient swings were too large for cases with eclipses
- Three aluminum structures were re-designed to have an additional 3kg of mass

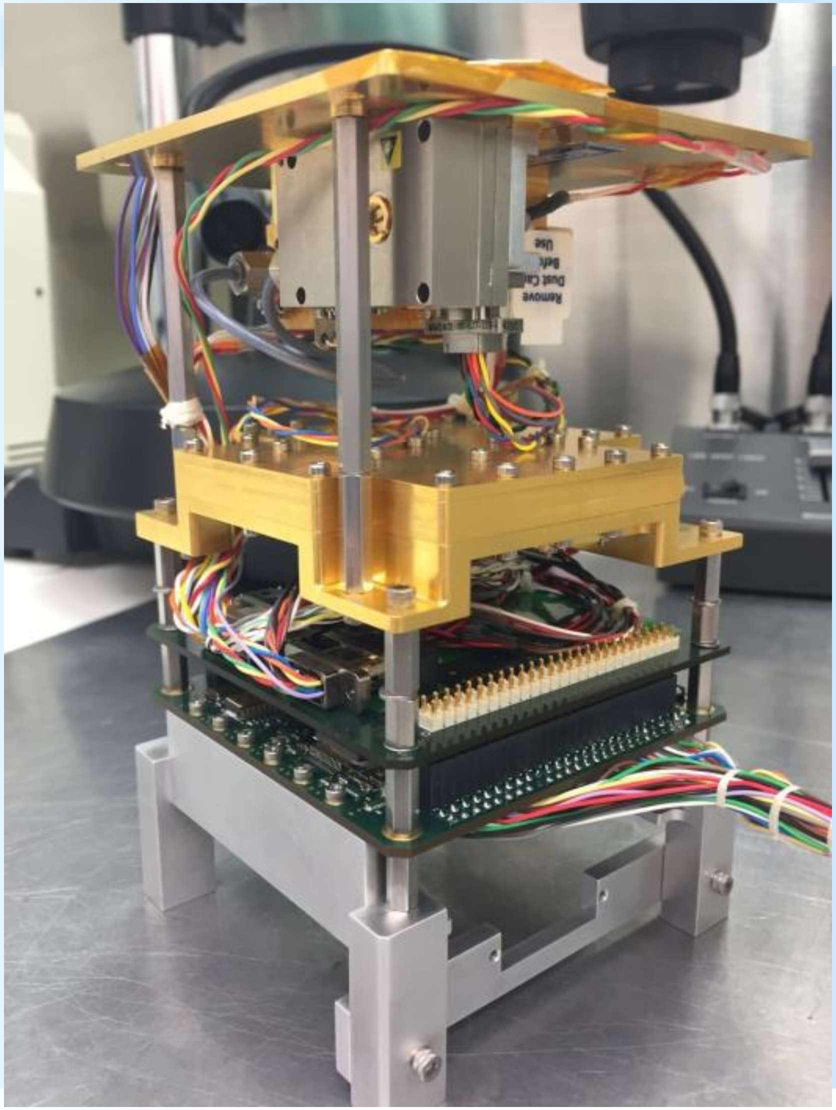
Cubesats at GSFC – How much TV testing should we do on low cost Class-D missions ?



Boom deployment will be done cold before this test. Chamber break between to re-configure

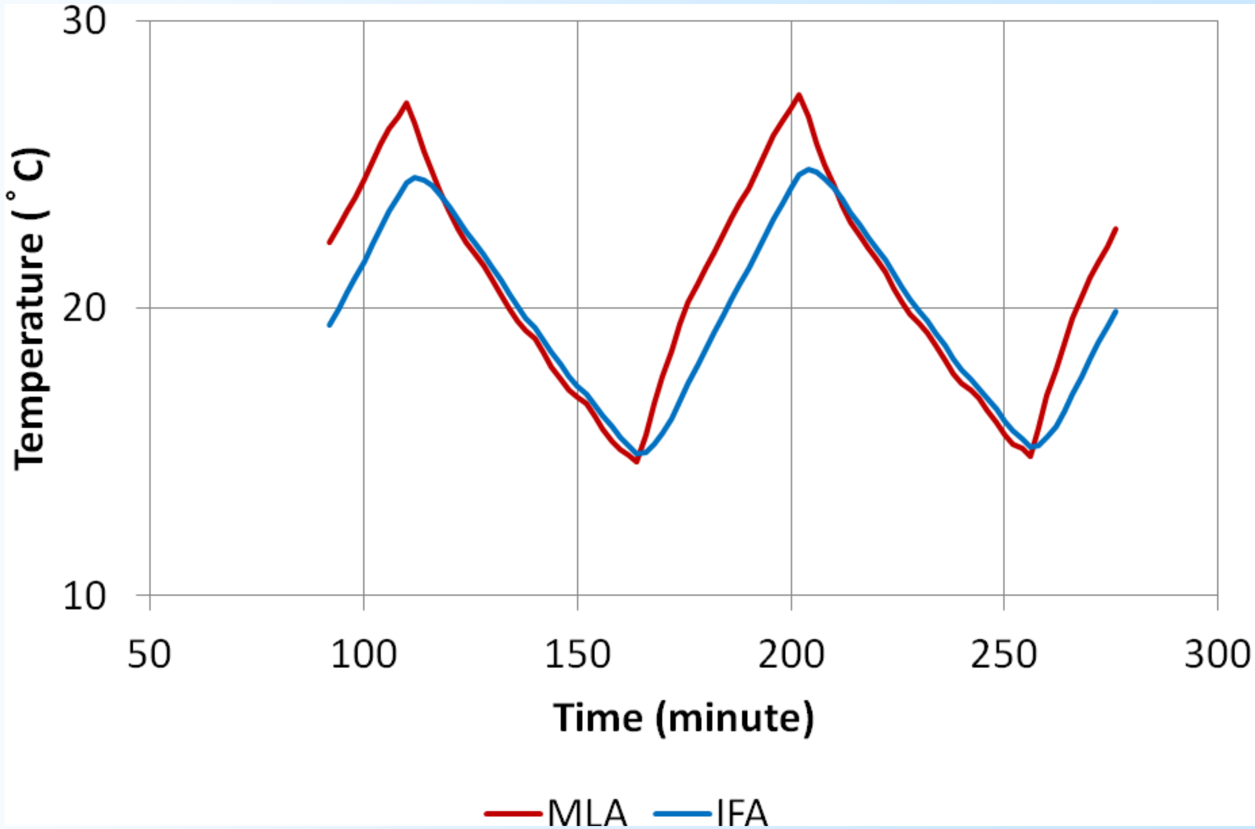
Cubesats at GSFC - ICECUBE



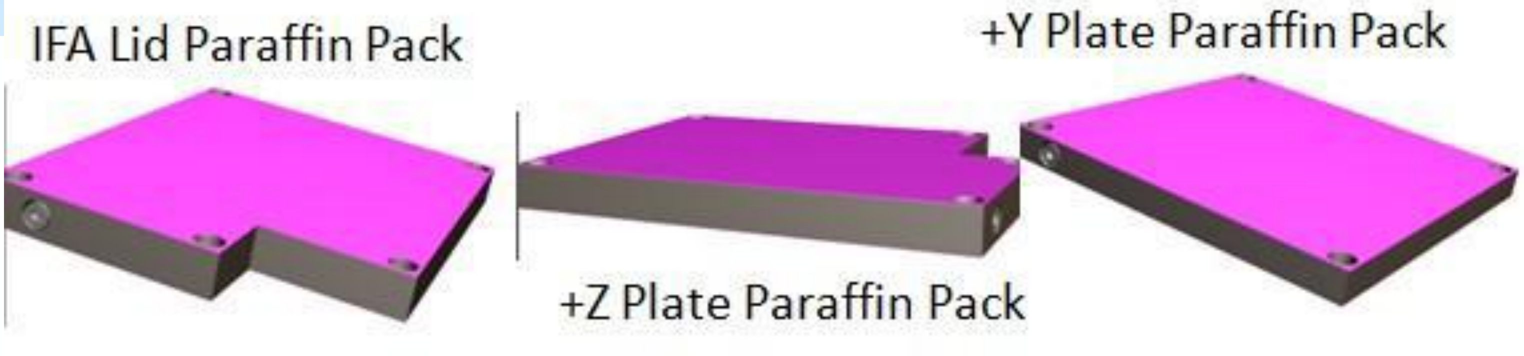


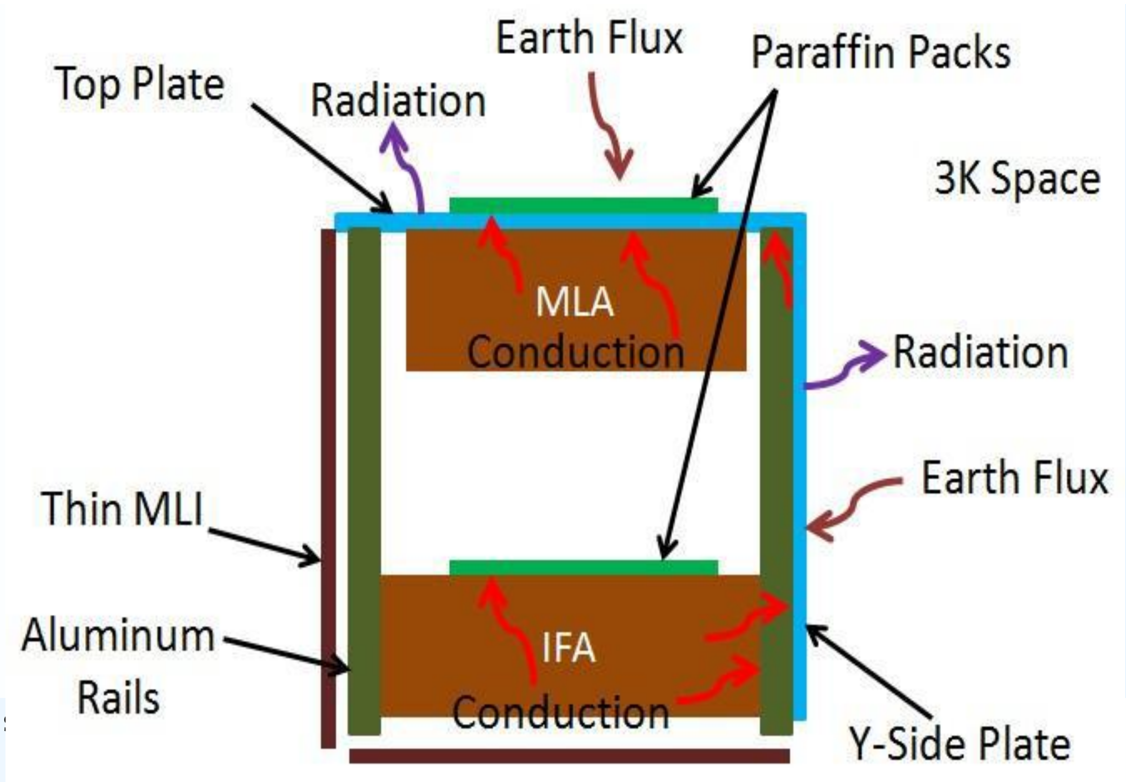
Cubesats at GSFC - ICECUBE

Initial prediction for MLA and IFA, but they require
20 +/- 1 C
PCM with heater Control added.

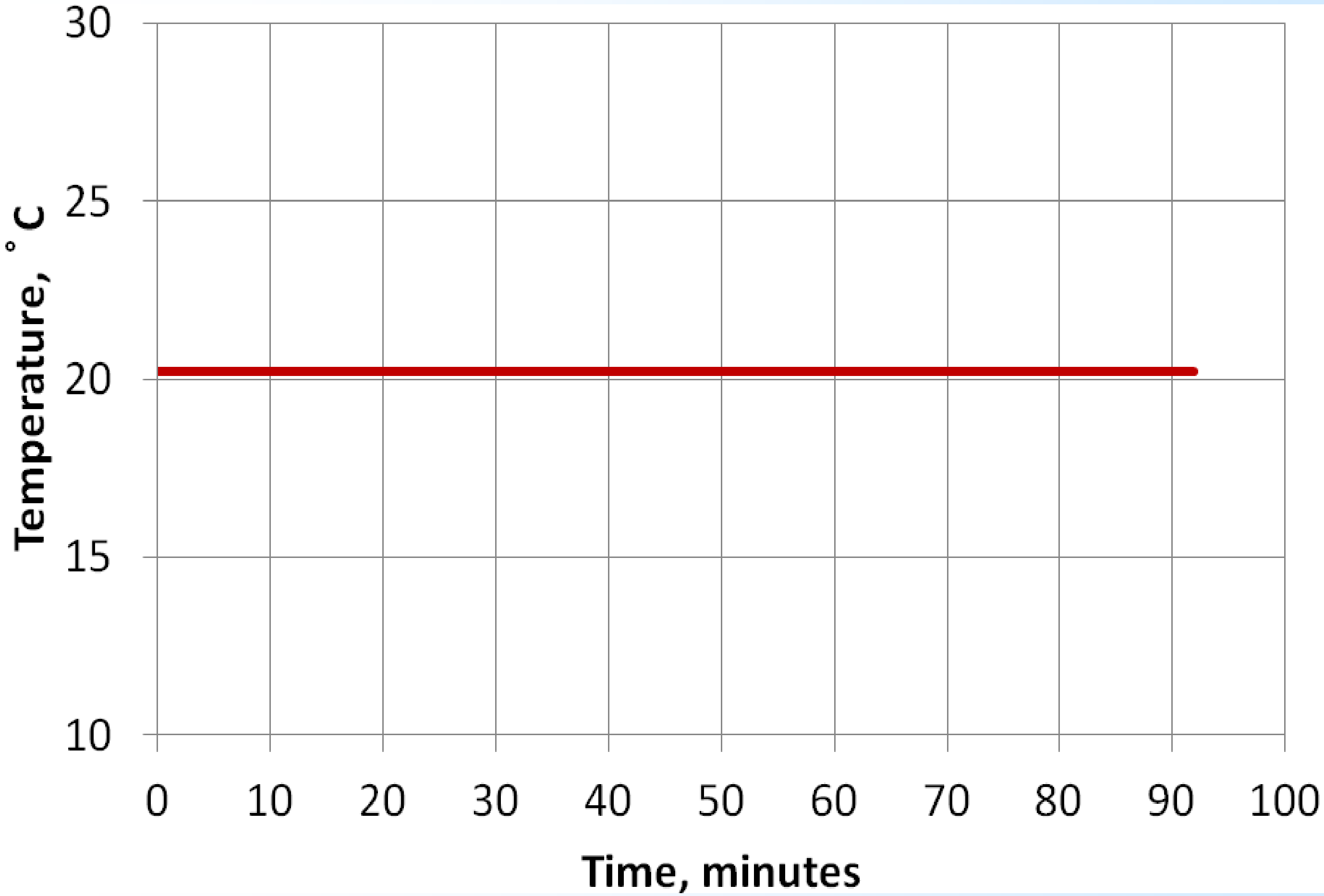


Cubesats – ICECUBE PCM by ESLI





Cubesats at GSFC - ICECUBE



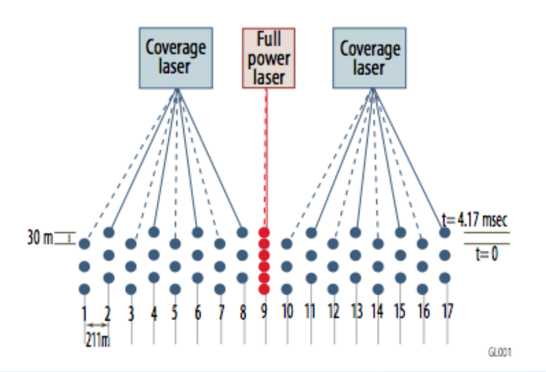
MLA and IFA predicts after PCM added

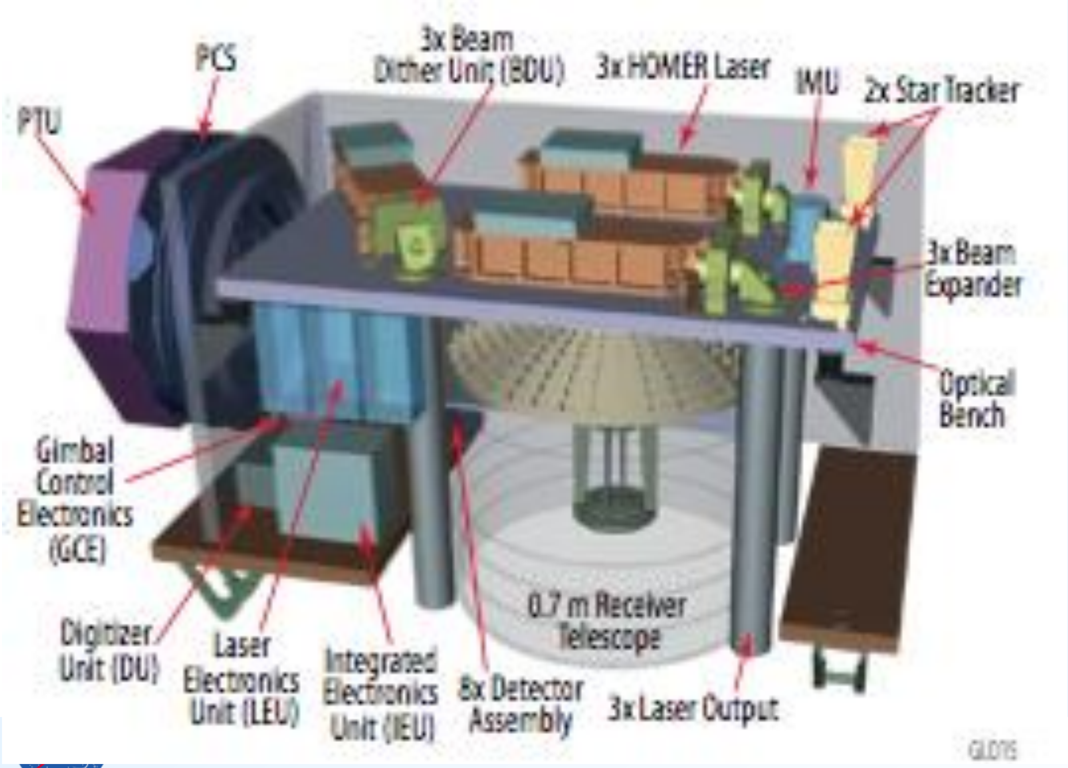
GEDI on ISS Overview

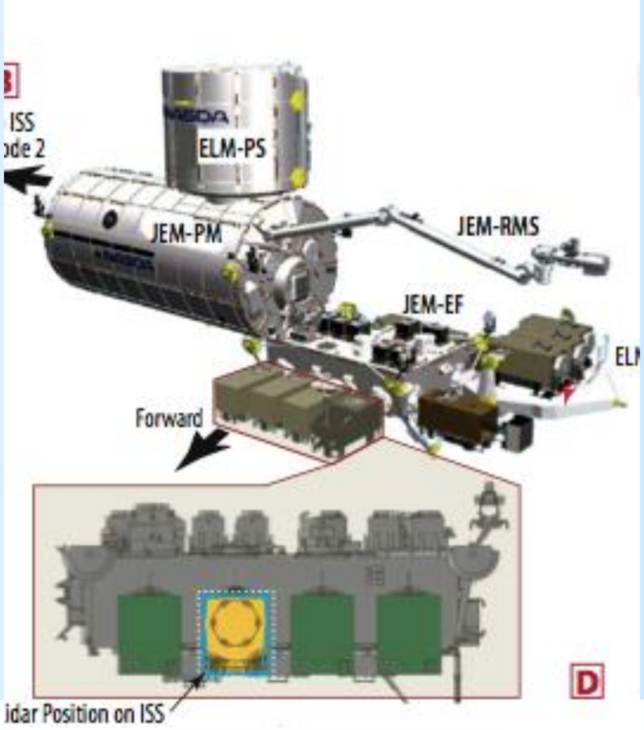
GEDI is a self contained laser altimeter

- 3 lasers produce 14 ground tracks

ISS Payload: Provides coverage of tropical and temperate forests



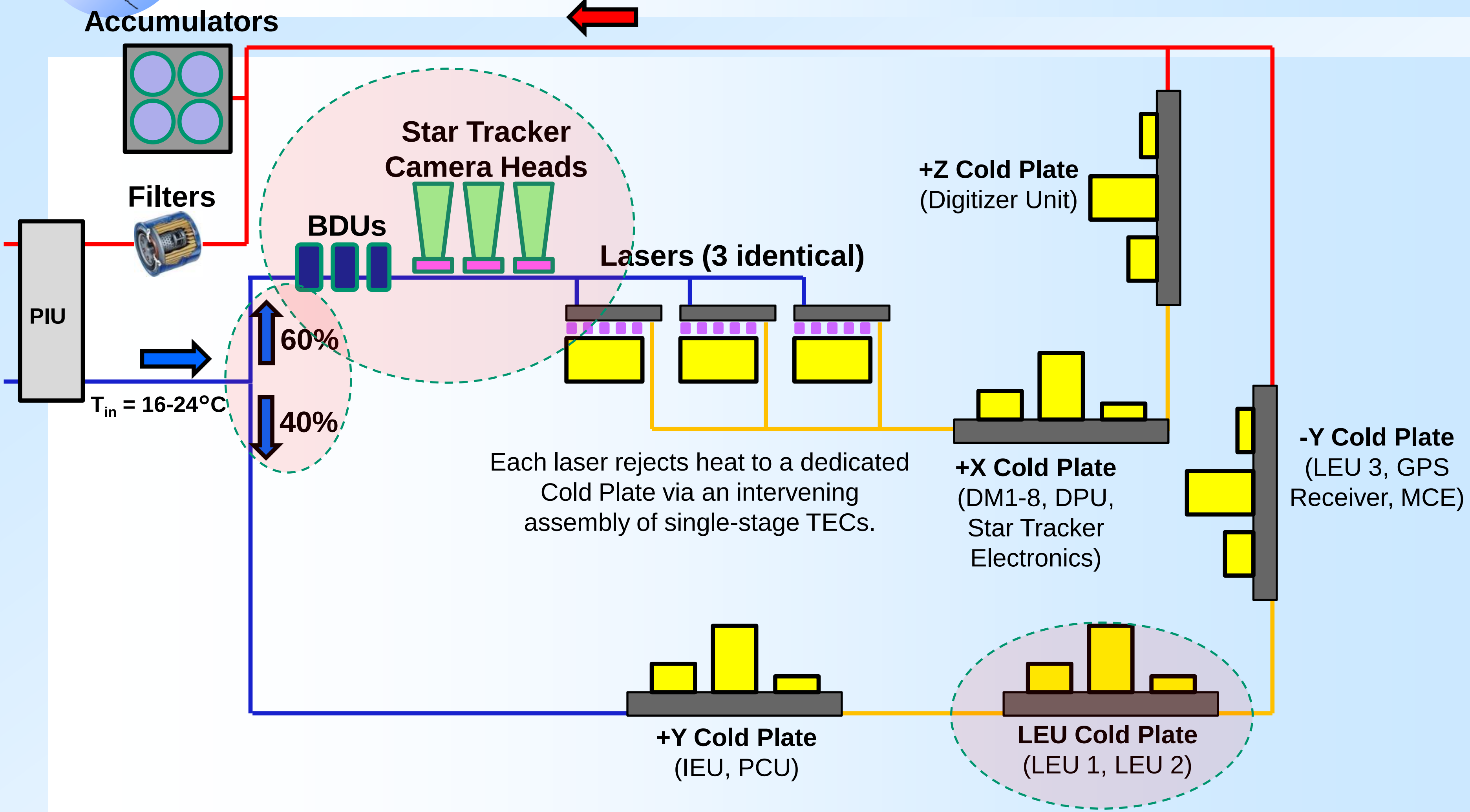




GEDI on ISS Overview

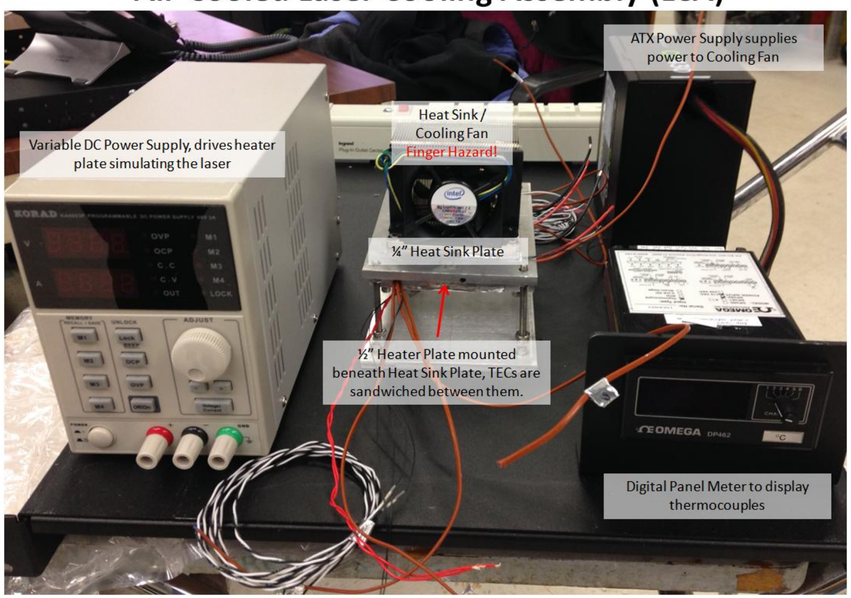
Dragon rendezvous with ISS, and berths to a module.
SSRMS SPDM pulls GEDI out of the Dragon Trunk
SSRMS hands off GEDI to the JEMRMS which installs GEDI to JEM

GEDI Cooling Loop Schematic

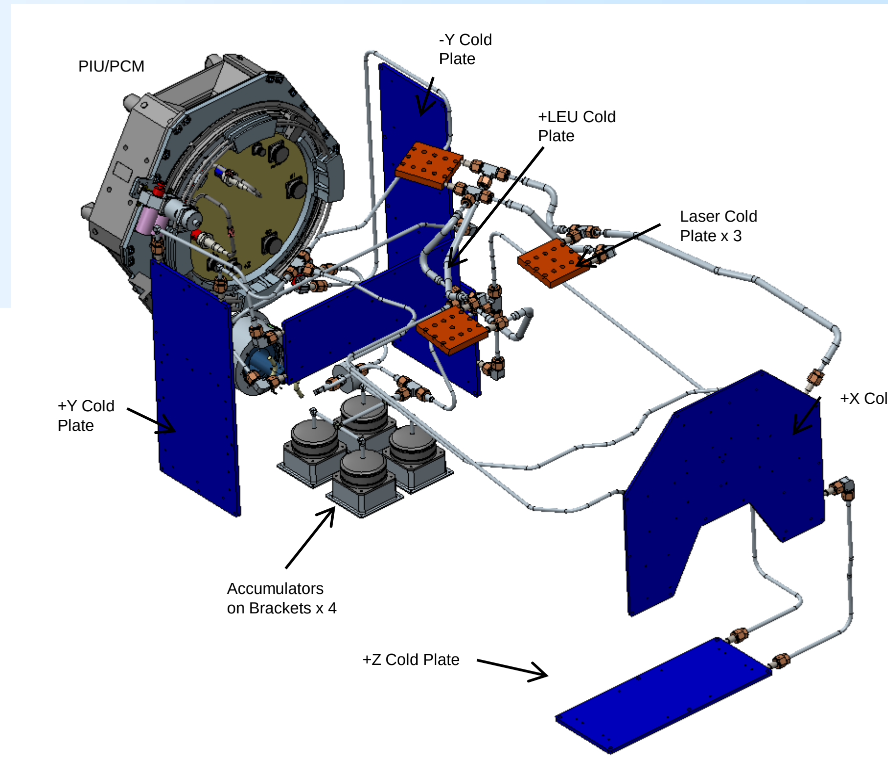


GEDI Ground Cooling Challenges

Air-Cooled Laser Cooling Assembly (LCA)



11 December 2015 Air-Cooled Laser Cooling Assembly, a.k.a. "TEC Sim" 6



Emerging Thermal Control Technologies

- GSFC's SBIR Thermal Subtopic had a robust 2015 with participation from 4 NASA centers, 26 Phase 1 proposals received for 2016
- IRAD funding received for 2 activities
- HQ funding for 1 activity

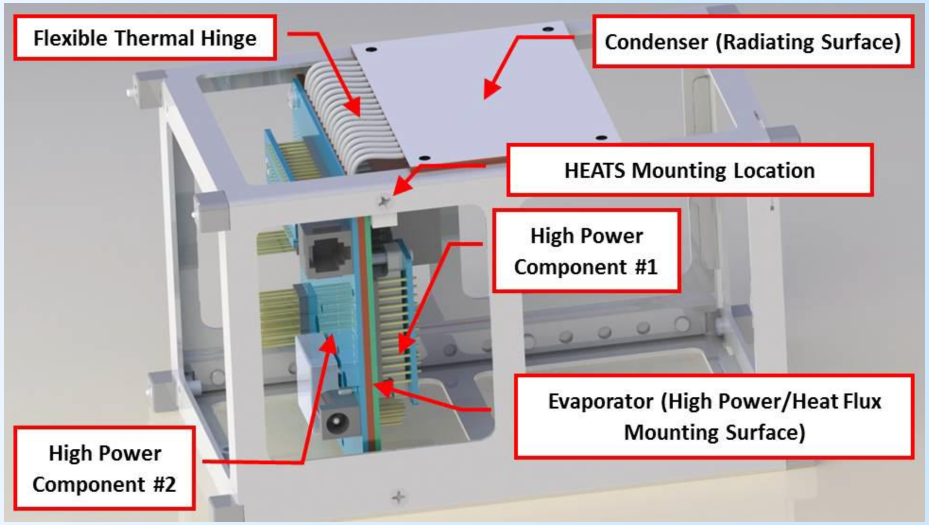
High heat flux Enhanced Acquisition and Transport system for Small spacecraft

LoadPath

Proposal#: S3.07-9621,SBIR 2015 Phase I (GSFC)

Description and Significance of Innovation

Future small-spacecraft thermal engineers and integrators will contend with increasing spacecraft power and temperature variations resulting from challenging new missions in extreme environments. The LoadPath High heat flux Enhanced Acquisition and Transport system for Small spacecraft (HEATS) is an innovative, passive, two-phase thermal transport system that will help realize these missions of tomorrow. Compared to the state-of-the-art thermal transport systems (e.g. heat pipes and loop heat pipes), this device has advantages of design simplicity, compact, low mass, and low cost. If developed successfully, this innovation would allow for optical instruments, high-voltage electronics, and other thermally-demanding components to be rapidly prototyped, integrated, tested, and flown on small spacecraft, thereby greatly benefitting future NASA missions.



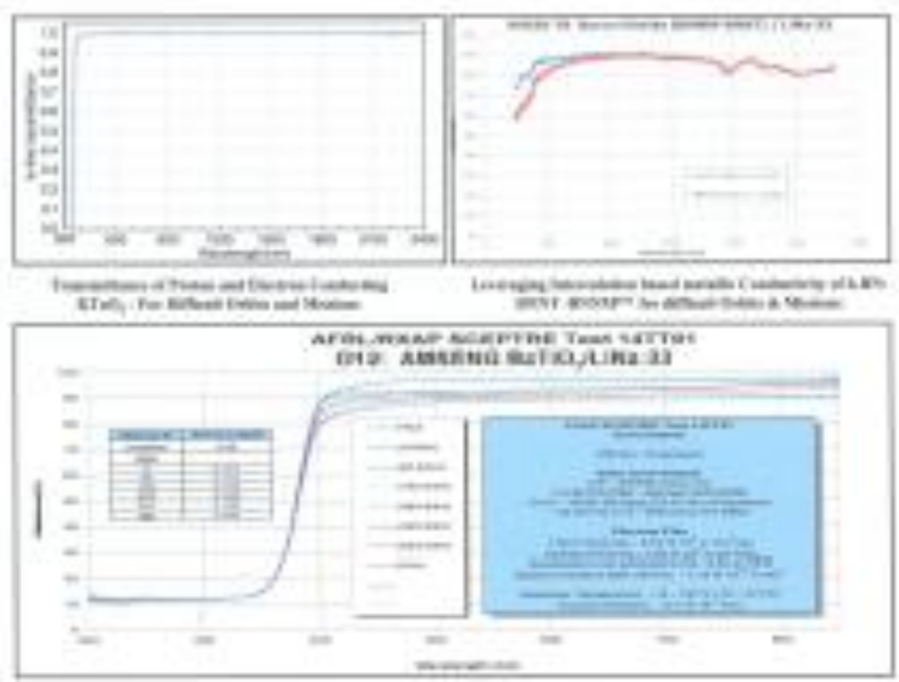
Innovations for the Affordable Conductive Thermal Control Material Systems for Space Applications

Applied Material Systems Engineering, Inc. (AMSENG) Proposal#: S3.07-9425,SBIR 2015 Phase I (GSFC)

Description and Significance of Innovation

Future Spacecraft and Instruments for NASA's Science Mission Directorate needs increasingly sophisticated thermal control technology. This innovative proposal is submitted to fulfill the needs identified in this solicitation for the following specific need: More sensitive instruments are being planned to put on small satellites resulting in increased requirements for high electrical conductivity on spacecraft instruments and surfaces. This has increased the need for advanced thermal control coatings, particularly with low absorptance, high emmittance, and good electrical conductivity which can enable us to carry high leakage current in space stable manner at affordable cost.

The objective of this proposal is to leverage IR&D activities at AMSENG on enhanced performance and affordability for TCMS needs, including: 1) Synthesis of intercalated h-BN; 2) Studies for Mixed Proton and Electron Conductors; and 3) TCMS based on Micro Encapsulated Nano Engineered BaTiO3.

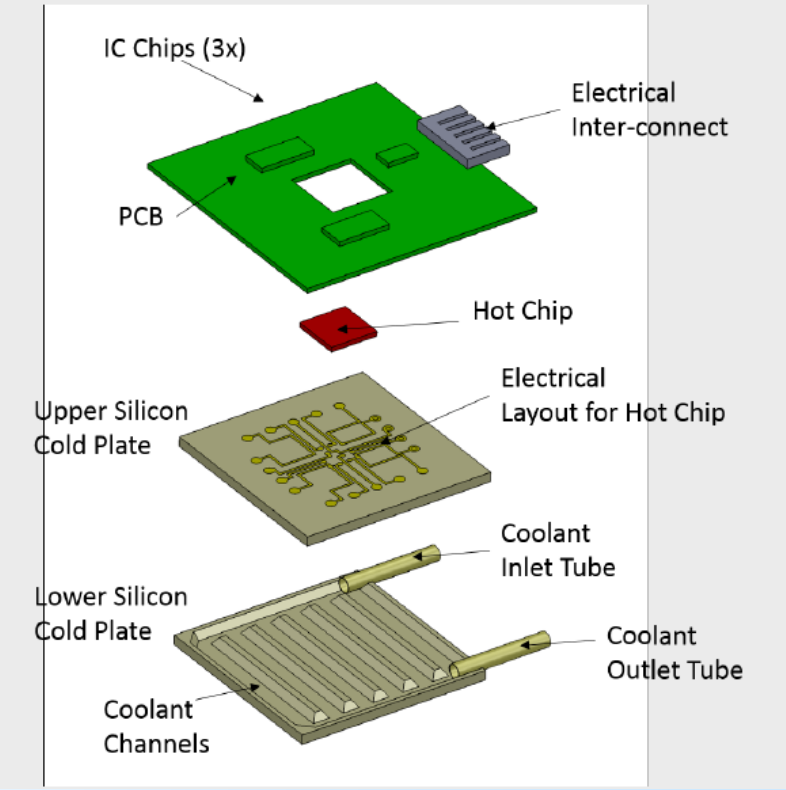


Silicon Cold Plate for CubeSat/SmallSat Thermal Control

EOTRON LLC
Proposal#: S3.07-9949,SBIR 2015 Phase I (LaRC)

Description and Significance of Innovation

The development of advanced small spacecraft with newer and more complex integrated electronics add to mission capability but also produce greater amounts of waste heat. Traditional methods of metal heat pipes or structures have size, weight and performance issues when scaling to accommodate higher thermal loads, especially in the vacuum and extreme conditions of space. Eotron has developed a 3D silicon front end to a fluid pump loop cooling system that offers improved performance in a compact and lightweight form factor. The proposed Silicon Cold Plate makes direct contact with high thermal flux devices and removes waste heat through a series of fluid channels internal to the silicon. Silicon's advantages of light-weight, high thermal conductivity and non-reactive nature to a variety of coolant liquids and gases make it ideal for CubeSat/SmallSat applications. In addition, utilizing existing flight proven pump systems will enable rapid TRL development.



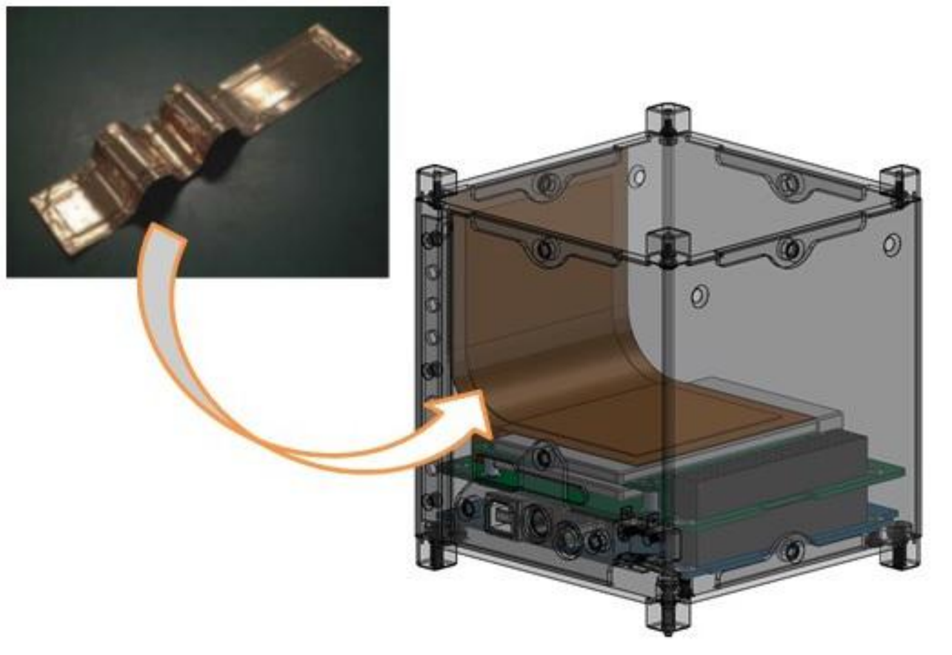
Flexible 2-Phase Thermal Strap for Small Sats

i2C Solutions

Proposal#: S3.07-9239,SBIR 2015 Phase I (MSFC)

Description and Significance of Innovation

A rapidly growing class of spacecraft are CubeSats and SmallSats. Current NASA missions indicate an equally rapid growth of technological capabilities to support these small spacecraft. Large deployable solar arrays and closely packed electronic suites are giving rise to an increasing demand for thermal management technologies in CubeSats and SmallSats. NASA is currently seeking thermal control technologies for this class of spacecraft, thus enabling revolutionary capabilities within small satellites. In response to the need for advanced heat transfer components for improved thermal management onboard CubeSats and SmallSats, i2C Solutions proposes to develop spacerated flexible 2-phase thermal straps with vacuum survivability and operational capability. The current effort will build upon current and previous DoD-funded developments of 2-phase thermal management components with thermal conductivities in excess of 1500 W/m-K and thicknesses of less than 1-mm.



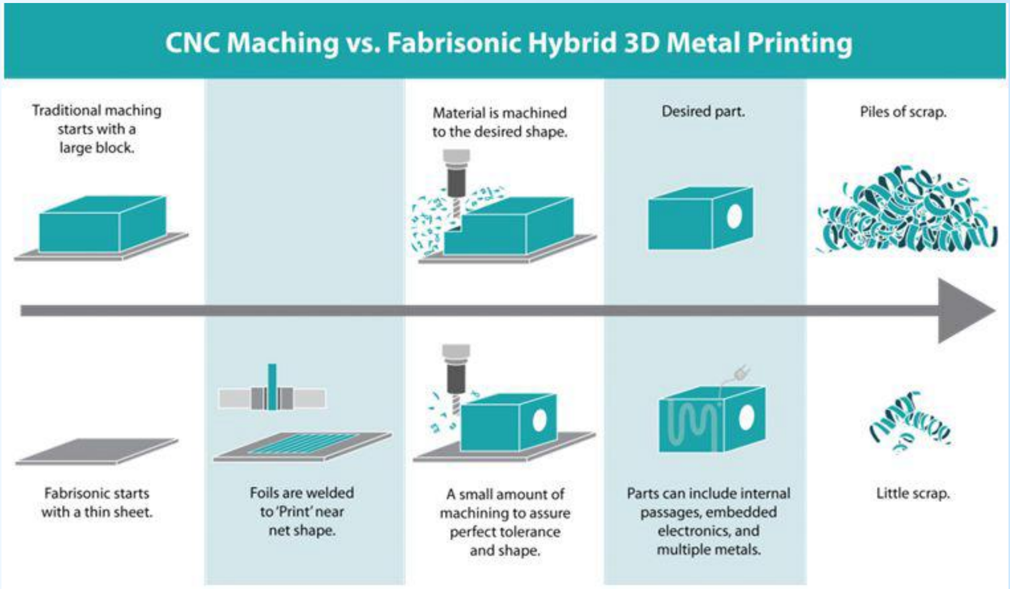
Ultrasonic Additive Manufacturing for Capillary Heat Transfer Devices and Integrated Heat Exchangers

Sheridan Solutions LLC

Proposal#: S3.07-9989,SBIR 2015 Phase I (JPL)

Description and Significance of Innovation

This proposal will demonstrate the use of Ultrasonic Additive Manufacturing (UAM) to 3D print aluminum structures with embedded thermal management passages for accommodating mechanical pumped fluid loop (MPFL) channels, integrated heat pipes, or other integrated wick/capillary systems. This technology has tremendous potential to revolutionize the way that complex heat exchanger structures are manufactured while further enabling advanced thermal control schemes that NASA is relying more upon for its missions. UAM has the following advantages: a) Reduces the time and costs to build complicated heat exchangers; b) Enables the design and construction of multidisciplinary structures that are mass optimized for both thermal and mechanical loads; c) Provides enhanced thermal efficiency of heat exchangers by placing the working fluid in direct metal contact with the article requiring thermal management (avoids use of epoxy for bonding tubing to panels); d) Enables unique construction of blended material heat exchangers (copper-aluminum, aluminum-stainless, titanium-aluminum)

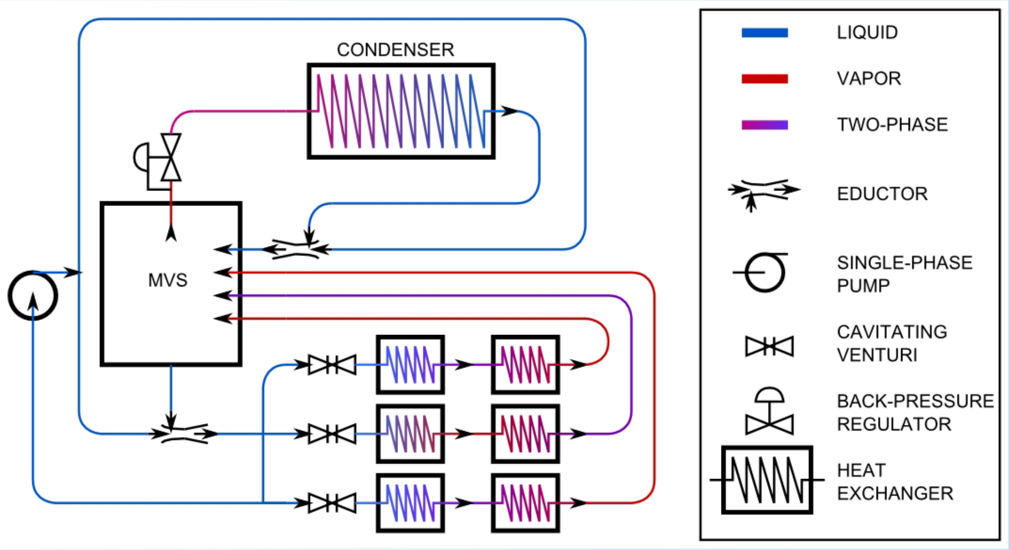


Two-phase Pumped Loop for Spacecraft Thermal Control

Advanced Cooling Technologies, Inc.
Proposal#: S3.07-9409,SBIR 2015 Phase I (JPL)

Description and Significance of Innovation

The company proposes the development of an active Two-phase Thermal Management System (TPTMS) that relies on a liquid pump to drive two-phase flow through multiple heat loads distributed in parallel and in series while providing phase management using the momentum of the working fluid. The use of a liquid pump to drive the system allows the working fluid to overcome large pressure drops with low power consumption. This feature provides the ability to transfer waste heat over large distances. Additionally, flow can be driven through multiple heat exchangers or cold plates to either collect or release thermal energy. Arranged properly, this feature allows for heat load sharing. Added to these benefits are those intrinsic to two-phase heat transfer: near-isothermal operation, a two order of magnitude increase in the heat transferred per unit mass and the ability to handle high heat fluxes. A key, novel feature of the innovation is the momentum-based phase separator that doubles as a two-phase accumulator. Controlling the saturation state of the accumulator, also sets the loop set-point.



GSFC IRAD Activities

Passive Films for Radiator Thermal Control

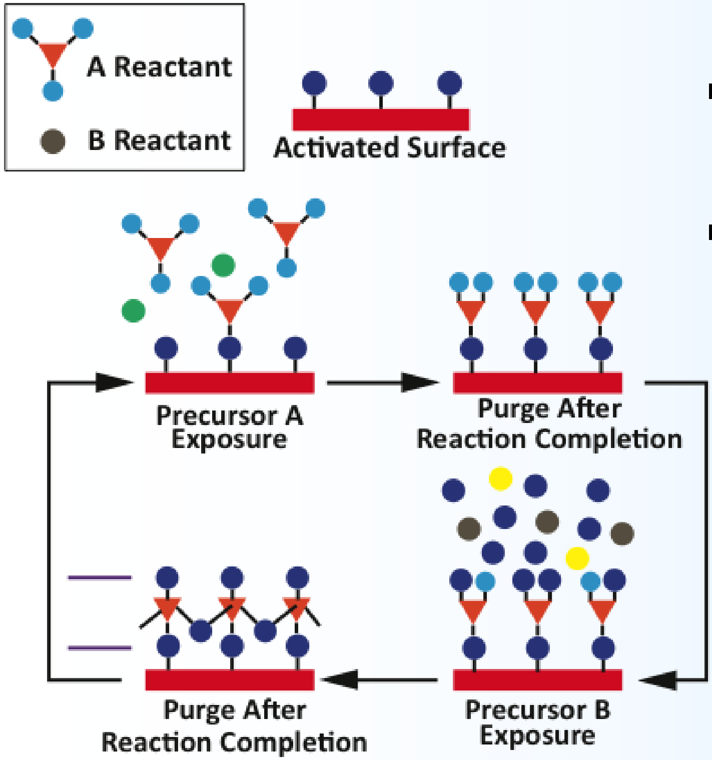
Dr. Vivek H. Dwivedi
Principal Investigator

Task Objective

Trending towards reduced power and mass budget on satellites with a longer mission life, there is a need for a reliable thermal control system that is more efficient and cost-effective. Vanadium dioxide, VO_2, is a transition metal oxide that undergoes a passive thermal phase change from a semiconductor to a metal at 67 C thus changing its thermal emittance. By depositing nm thick VO_2 via an in house atomic layer deposition (ALD) reactor, passive thermal control for solar cells, radiators and external boxes can be achieved with minimized weight.

ALD – Atomic Layer Deposition

A thin film"nanomanufacturing" tool that allows for the conformal coating materials on a myriad of surfaces with precise atomic thickness control.



- Paired gas surface reaction chemistries
- Benign non-destructive temperature and pressure environment
  - Room temperature -> 250 ° C (even lower around 45 ° C)
  - Vacuum

Vanadium Oxide

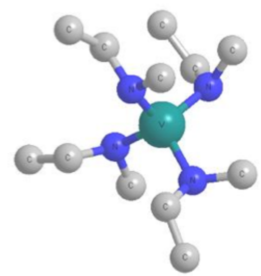
- VO2 is a thermochromic material that changes froma semiconductor to metallic with increasing temperature
- It is generally deposited on IR transparent substrates like Si, quartz, and Al2O3. The transition that occurs at about 68 C is accompanied by an increase of IR reflectivity and a decrease of IR emissivity with increasing temperature

- In-situ XRD reveals structural transition:
  - Low T: VO_2 (M1)
  - High T: VO_2 (R)
  - $T_{transition}$: 67°C
  - Hysteresis: 12°C
- In-situ resistivity:
  - R(30°C)/R(100°C) ~ 200
  - $T_{transition}$: 63°C
  - Hysteresis: 12°C

ALD VO2

- **Precursors: Proprietary vanadium source from Air Liquide – TEMAV and Ozone**

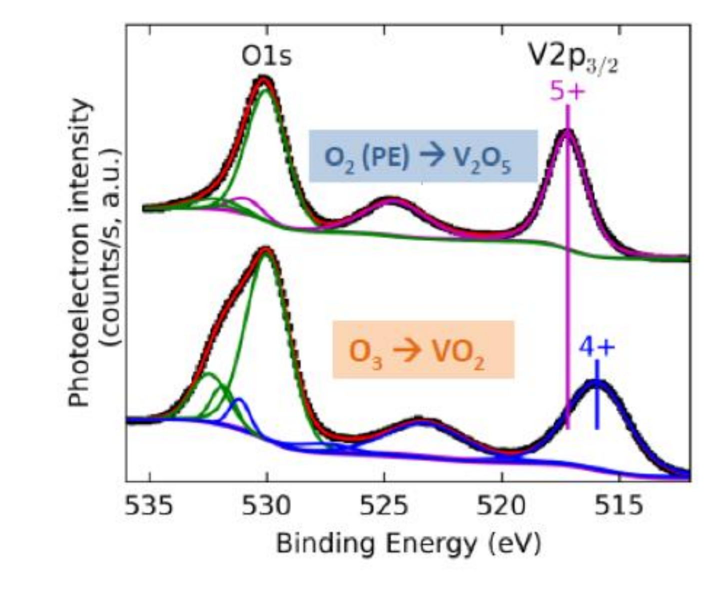
- Product name: TEMAV
- Real chemical name: Tetrakis(ethylmethyl)amido Vanadium (IV)
- CAS#: not established
- Formula: $V(NEtMe)_4$



Properties

- Dark liquid
- Vapor Pressure: 1.12 Torr @ 100°C
- TGA

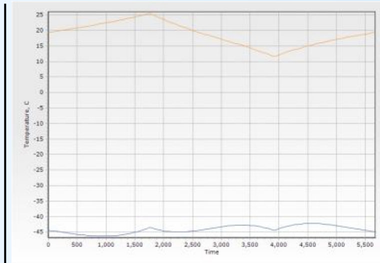
TGA Residue % (@ 400 °C)		
oc	cc	vac
1.5	13.7	0.6

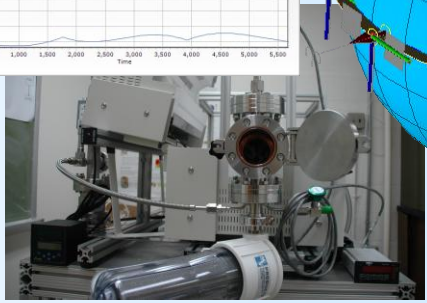


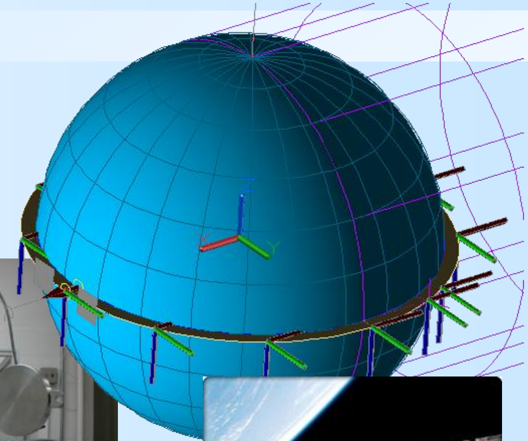
Passive Thermal Films

Description and Objectives:
Trending towards reduced power and mass budget on satellites with a longer mission life, there is a need for a reliable thermal control system that is more efficient and cost-effective. Vanadium dioxide, VO_2, is a transition metal oxide that undergoes a passive thermal phase change from a semiconductor to a metal at 67 C. By depositing nm thick VO_2 via an in house atomic layer deposition (ALD) reactor, passive thermal control for solar cells, radiators and external boxes with minimized weight.

Key challenge(s)/Innovation:
By utilizing a novel liquid based vanadium source deposition is possible in benign environments. By adding ALD based dopants temp transition will trend low.







Approach:
Demonstrate the applicability of a custom built in-house ALD system to coat crystalline vanadium oxide films as well as films of doped vanadium oxide via an ALD doping technique to achieve a transition temperature at or below 67 C. Test the transition temperature using a cost effective set-up.

Application / Mission:
- CubeSat (LWaDI)
- Radiators
- Shape Shifting Radiator

Collaborators:
Raymond Adomaitis (UMD), NRL, Code 695

Milestones and Schedule:
- Reactor Check-out Dec 2015
- VO2 Growth March 2016
- Full Characterization (End Summer 2016)

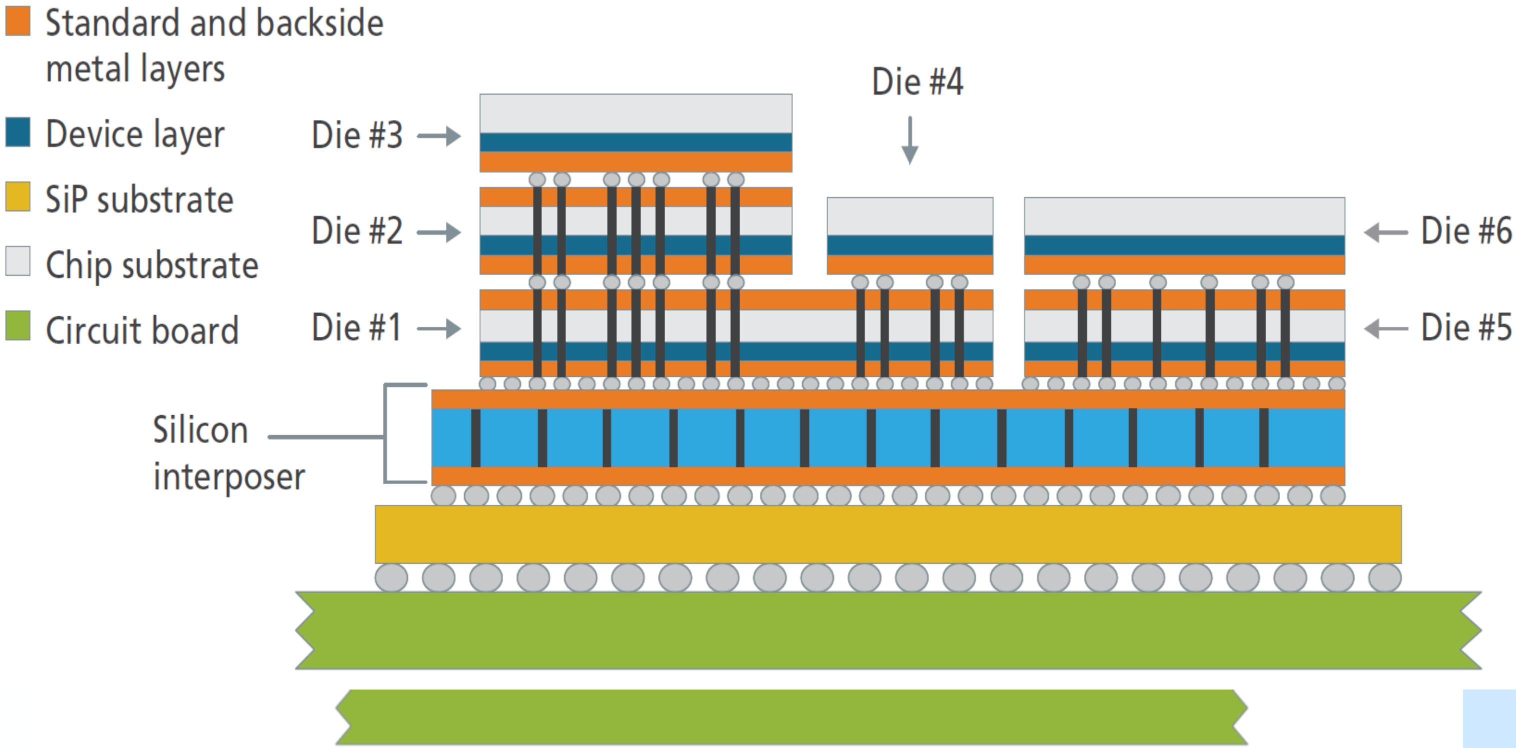
Space Technology Roadmap Mapping:
- Primary Technical Area: TA14
- Secondary Technical Area: TA10
- Additional Technical Area(s): TA12
- Applicable Space Technology Grand Challenge: Surviving Space Environments

Technology Readiness Level:
- Starting TRL: 3
- Anticipated Ending TRL:6

Flow Boiling in Microgap Coolers – an Enabling Technology for 3D Integrated Circuits

Frank Robinson
Principal Investigator

What is a 3D IC?

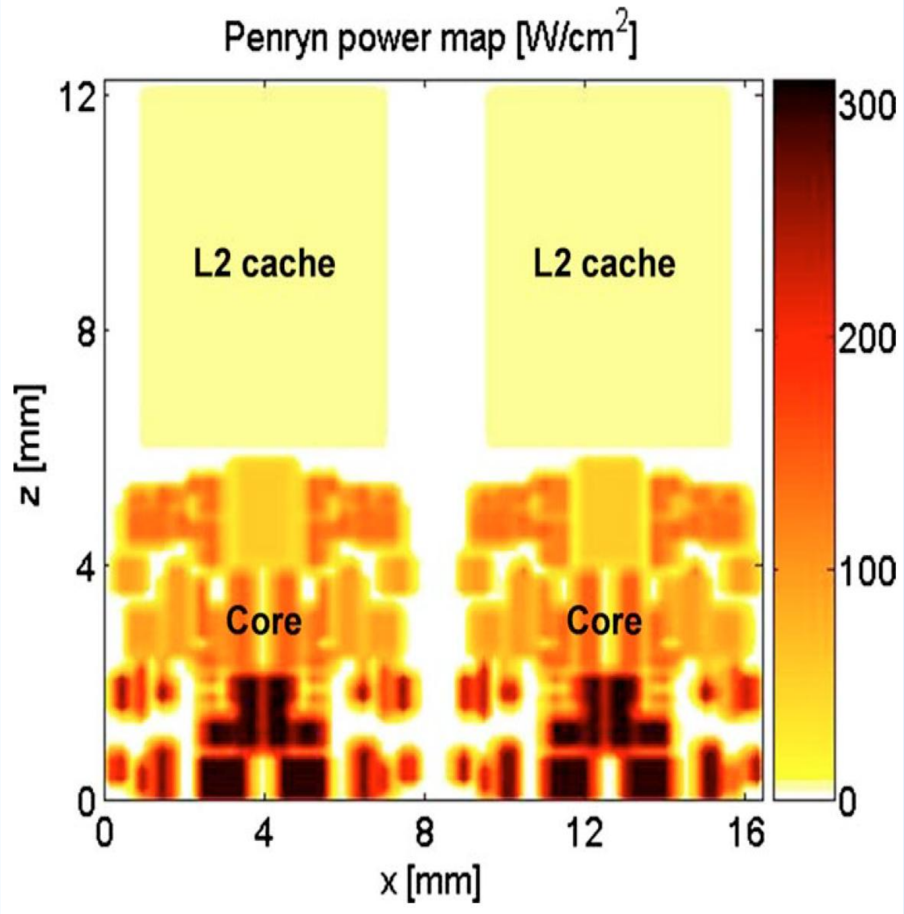


- Vertically-integrated stack of active electronic components
- Heterogeneous devices

- TSV implementation
- Based on existing lithography

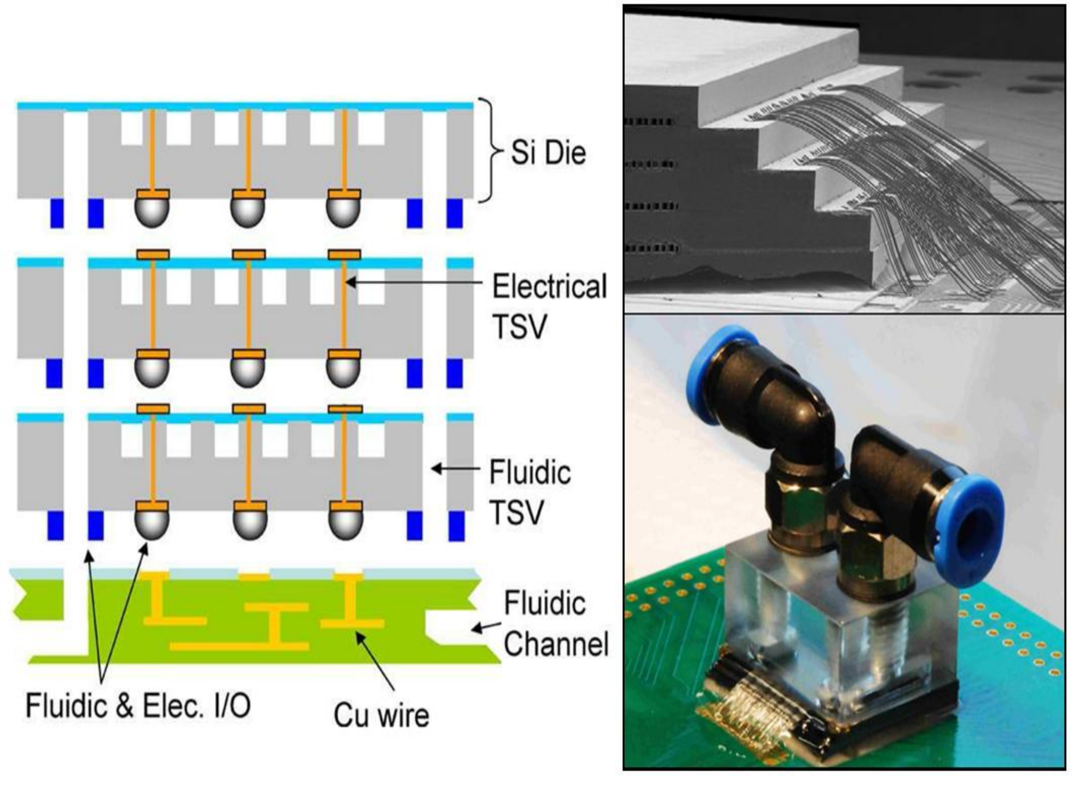
Emerging Thermal Challenges

- Chip dissipation > 100W
- Local hot spots > 1 kW/cm^2
- Stack generation > 1 kW/cm^3
- Non-uniform heating
- Small spacing between adjacent chips ($\Delta P \sim d^{-4}$)



Flow Boiling in Micro-Coolers

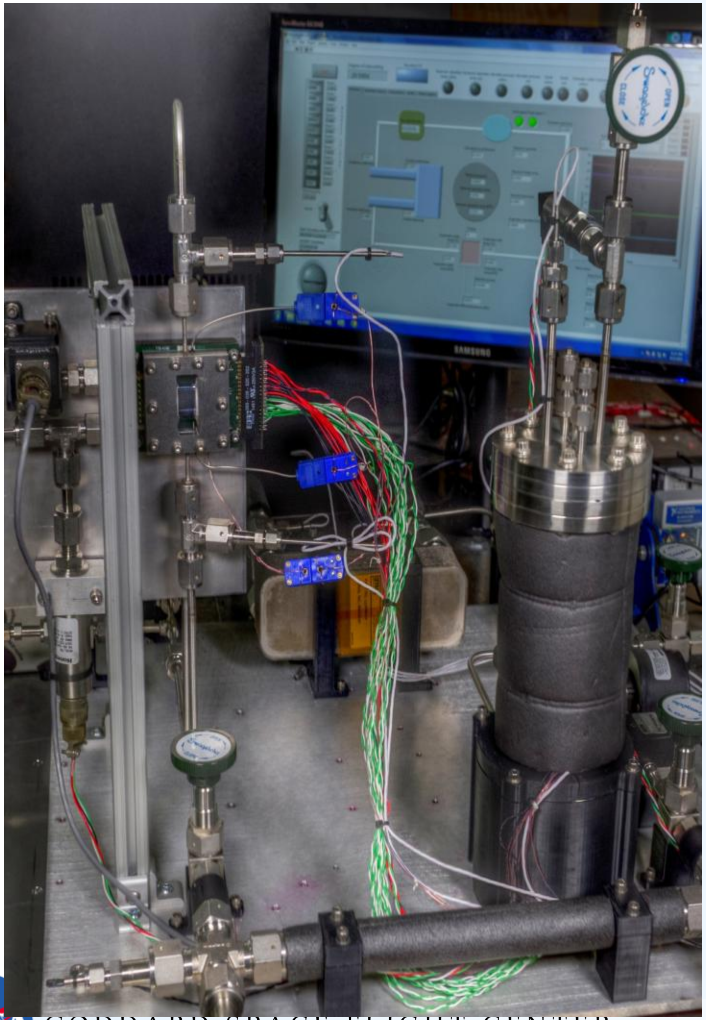
- Passive two-phase at TRL9
- Active two-phase for higher heat fluxes, higher heat loads
- Thermal + microgravity validation required (TRL3)

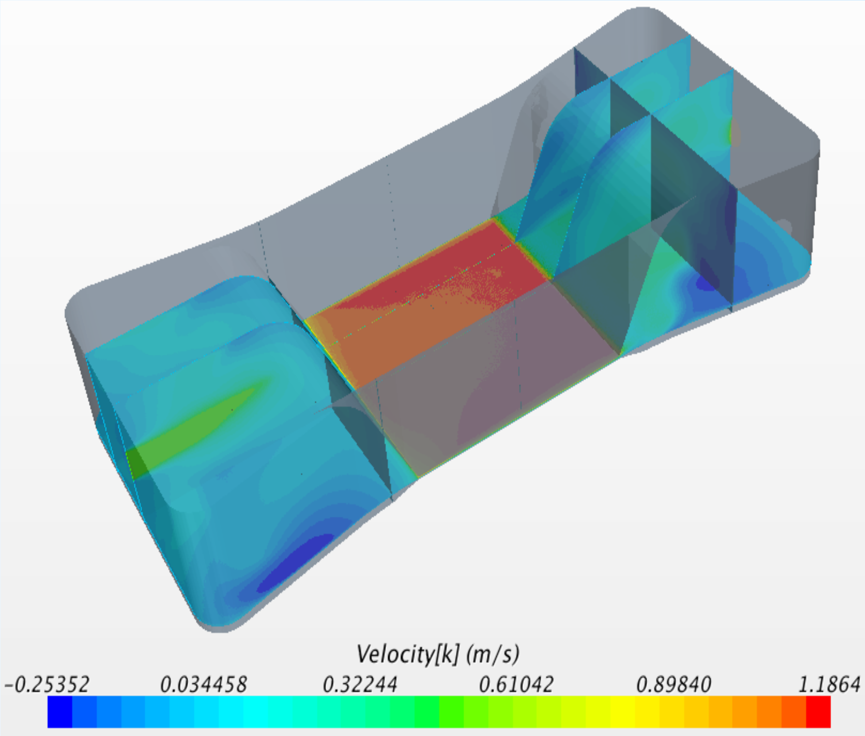


FY16 Goals

1. **Characterize thermofluid performance of two-phase microgap coolers for 3D IC and other power dense applications**
2. **Assess sensitivity of two-phase flows in small channels to orientation and g-loading**

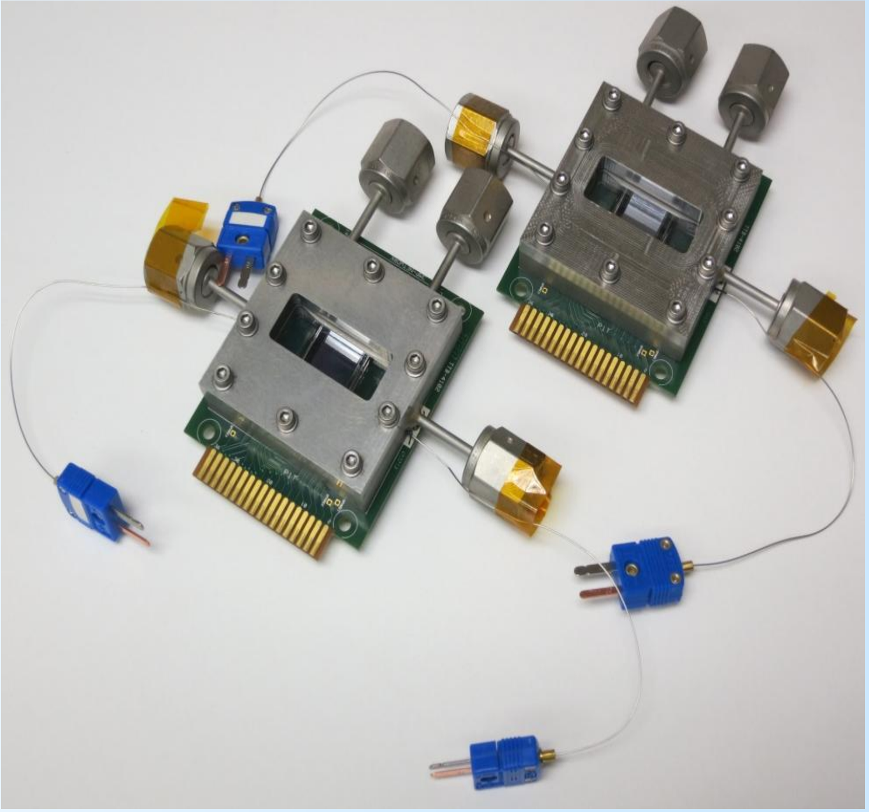
Approach





Recent Progress

- Replaced reservoir control heaters
- Upgraded overtemperature protection circuit
- Two improved flow enclosures assembled, ready for orientation testing



Technology Development

Embedded Thermal Control Subsystems for Next Generation Spacecraft Applications

Jeffrey R. Didion
Senior Thermal Engineer
Manager, Nanotechnology Facility

– Details can be found in Jeff's Presentation

SUMMARY

- New Technology program underway at NASA, although funding is limited. Revised Roadmaps developed
- NASA/GSFC’s primary mission of science satellite development is healthy overall, although new missions are in work – GSFC work is slow in the I&T area.
- Future mission applications promise to be thermally challenging
- Direct technology funding is still very restricted
  - Projects are the best source for direct application of technology
  - SBIR thermal subtopic resurrected in FY 14, continued in FY 15 and FY 16
  - Limited Technology development underway via IRAD, NESC, other sources